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ABSTRACT

"Outlook" publications focus on areas of science and technology in which research can be valuable to industry, government, and society as a whole. This issue deals with the problems of air pullution and air quality control. The first of six essays,". . . This Most Excellent Canopy, the Air," prognosticates the surge in atmospheric pollution and calls for appropriate legislation, adequate monitoring, and effective enforcement of regulations. Approaching the problem of identifying pollution-prone areas and dealing with them is covered in "The Regional Approach to Air Quality Control." Although the internal combustion engine is identified as the greatest single source of air pollution, the auto industry appears reluctant to switch to an alternative power plant as noted in "Air Pollution From Motor Vehicles." "Solving the Riddle of Smog," assesses photochemical smog, focusing less on how many hydrocarbons get into the air and more on how harmful are the emitted hydrocarbons. Problems involving large-scale generation of electricity and developing acceptable combustion systems are explored in "What About Air Pollution by Power Plants?" The final selection, "Episode: A Case of Applied Atmospheric Dynamics," relates a fictitious story of how one community attacked its air pollution problems. Miscellaneous notes and research briefs complete the publication. (BL)

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Battelle Research Outlook

Cleaning Up the Atmosphere

Volume 2 · Number 3 · 1970

The Battelle Research Outlook focuses on areas of science and technology in which research can be valuable to industry, to government, and to society as a whole. Its purpose is to point up significant current problems in those areas and to suggest effective research approaches to their solution. The Outlook is published quarterly by the Columbus Laboratories of Battelle Memorial Institute, an organization advancing and utilizing science and technology for the benefit of mankind through technological innovation.

Battelle Research Outlook

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"...This Most Excellent Canopy, the Air,

look you, this brave o'erhanging firmament,
this majestical roof fretted with golden fire,
— why, it appears no other thing to me
than a foul and pestilent congregation of
vapours. . . ."

Hamlet

by Frank A. Butrico, Richard B. Engdahl, and Carl J. Lyons

As HAMLET DESCRIBED the atmosphere around him, the castle of Elsinore might well have been located near almost any industrial city of the 20th Century. Urban Americans would feel right at home under Elsinore's atmospheric "canopy."

If theory is correct, the earth's atmosphere once was deadly methane and ammonia. By some marvelous transformation it changed to the breath of life — basically, 21 percent oxygen, 78 percent nitrogen, and traces of several other gases. Carbon dioxide, so essential to the food cycle, makes up a mere 0.03 percent of the total. Vital water vapor ranges from 0.05 to 5 percent. If these tiny proportions were lost, life might indeed disappear.

The atmosphere performs other important functions. It shields us from harmful radiation, tempers and retains the sun's heat, and disperses particulate matter, including life-carrying spores and seeds. Nor should we value too lightly the play of lights and cloud shadows and the colorful artistry of this canopy — in buoying the human spirit.

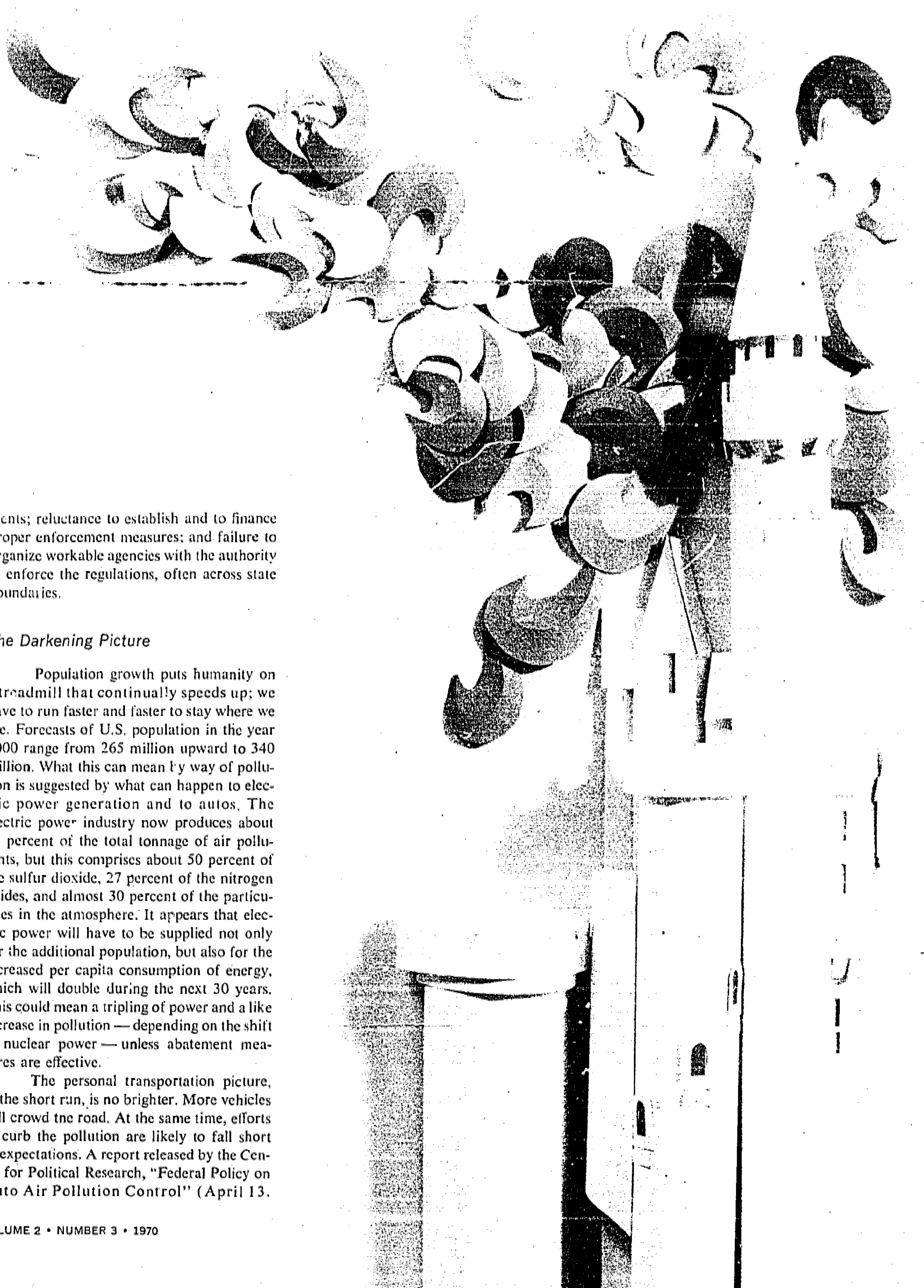
Moreover, Nature has always known how to keep her air clean. The atmosphere has dealt with dust and gases from volcanoes. It has picked up methane from decaying vegetation and terpenes from pine forests. The atmosphere has ways of cleansing itself of such materials. Over the centuries, man has used the atmosphere to dispose of much of his gaseous and particulate wastes. But unlike Nature, which generates airborne refuse in amounts that the atmosphere can handle easily, man has set no limits. The results: the overloaded atmosphere frequently fails to carry away the noxious wastes as quickly as we produce them, so they can pose serious threats to us.

SPOILING THE ATMOSPHERE

Science and technology have provided the means for overloading the atmosphere. Industries belch a witch's brew of airborne wastes; the geometric increase in the need for electric energy multiplies power generating plants; and the smog-producing automobile is omnipresent. These and other sources of pollution, which propagate as the population expands, give an unending vista of atmospheric fouling.

Each year, the U.S. alone pollutes the skies with over 200 million tons of waste products. Certain steps have been taken to control this pollution: standards have been set in some fields; Federal and state regulatory bodies have been created; industry already has spent billions on significant cleanup; research is under way in many laboratories; and the public is being alerted and informed.

Nevertheless, the possibilities of dramatically improving the quality of our atmosphere are not promising. It is true that much of the technology needed is already available and is being applied; broader use of today's knowledge and techniques would improve conditions greatly. Moreover, there seems to be no reason to question the ability of industry, science, and technology to carry out the tasks that will confront them in the years ahead. The real difficulties are: hesitation to set up truly realistic standards and require-



ments; reluctance to establish and to finance proper enforcement measures; and failure to organize workable agencies with the authority to enforce the regulations, often across state boundaries.

The Darkening Picture

Population growth puts humanity on a treadmill that continually speeds up; we have to run faster and faster to stay where we are. Forecasts of U.S. population in the year 2000 range from 265 million upward to 340 million. What this can mean by way of pollution is suggested by what can happen to electric power generation and to autos. The electric power industry now produces about 13 percent of the total tonnage of air pollutants, but this comprises about 50 percent of the sulfur dioxide, 27 percent of the nitrogen oxides, and almost 30 percent of the particulates in the atmosphere. It appears that electric power will have to be supplied not only for the additional population, but also for the increased per capita consumption of energy, which will double during the next 30 years. This could mean a tripling of power and a like increase in pollution — depending on the shift to nuclear power — unless abatement measures are effective.

The personal transportation picture, in the short run, is no brighter. More vehicles will crowd the road. At the same time, efforts to curb the pollution are likely to fall short of expectations. A report released by the Center for Political Research, "Federal Policy on Auto Air Pollution Control" (April 13.

1970), notes two factors that counter control: (1) emission control devices on cars deteriorate with driving—after 11,000 miles of driving, 53 percent of originally new cars failed to meet the modest emission standards of 1968; and (2) state governments are not adopting inspection and enforcement procedures. No state has applied for federal funds offered to help start inspection programs.

A factor further intensifying the problem is the expanding use of mechanized servants. In industry, every new process and machine add to the demand for more energy as mechanical and especially electric power replace human muscle. Leisure and recreation activities also are using power sources more and more. Labor-saving devices inside the home are multiplying; power mowers, snow buggies, dune buggies, and the like increase the atmospheric trash; and more powered devices are crowding the market. These, too, must be considered.

The Burden of Cost

If man continues to spoil the atmosphere, it will be because he has neither accepted the need to improve the environment nor faced up to the cost of doing so. But pay for it he must, both through higher taxes and higher consumer prices. President Nixon already has suggested that "to the extent possible, the price of goods should be made to include the cost of producing and disposing of them without damage to the environment."

The feeling is growing in Congress that those who damage the environment should pay user fees to repair it. Such an approach would require careful study of the factors that are significant in setting equitable charges and in developing systems that would monitor the pollutants efficiently.

However they are paid, the charges will be large. The costs of eliminating fly ash emissions from electricity generating facilities — about 80 percent of these are already controlled — figure out to nearly $1 billion per year. An additional billion or more will be needed annually to remove sulfur dioxide from flue gases after present R & D efforts succeed. Applying foreseeable controls to autos will take $800 million, and another $350 million will have to be spent yearly for only the air cleaning part of rubbish incineration. Thus, curbing only these four types of pollution will cost over $14 per person annually. Paying for other measures that will be necessary in industry will raise the tab further.

Industry in the U.S. already is carrying a considerable burden for pollution control. In 1966, some $235 million was spent on the equipment for handling air pollution alone; with installation, the total came to $500 million. Currently, such expenditures run about $750 million annually. These sums relate primarily to catching-up steps. At the same time, the cost of most new plants that are being constructed include a 10 percent item for pollution control.

As U.S. consumers feel the bite of these costs, they are learning that some of the affluence of modern life has been wrung from Nature through insults to the environment. The toll that Nature exacts will depend largely upon the speed and effectiveness with which we make restitution for the insults.

WHAT'S NEEDED?

The job of cleaning up the atmosphere isn't simple or cheap, and it won't get done quickly. Being an effort of national — even international — proportions and requiring state and local cooperation, it will require new administrative machinery to coordinate and carry out the various tasks. Some standards have been established; more meaningful and more flexible ones are needed.

Cleansing the atmosphere will entail scientific and technological activities on a massive scale that will extend far into the future. We don't have to sit and wait for panaceas to emerge from the laboratories; today's state of the art offers many valuable lines of attack that have not been put to use for various reasons. But, new knowledge will be sorely needed just to stay even as the future unfolds.

Further, improving the air will have to be tied in with clean up work in other areas of pollution. Just as the ecosystem is made up of interacting realms, so repairing the atmosphere is intertwined with the measures that must be taken to reduce land and water pollution.

Machinery for Regulating Pollution

Who can disagree with the oft-stated philosophy that the control of pollution calls for collaboration among all sectors of society, public and private? Take the matter of paying the costs. Few communities can finance their own pollution controls even with Federal participation. In the last analysis, truly effective controls will require expansion of

both private and public financing, and the regulatory machinery should make such joint financing possible.

A fertile approach to dealing with multistate problems is to create regional authorities with broader planning and regulatory functions than present agencies enjoy. Such authorities will need powers to design, finance, construct, and operate treatment facilities that other public or private organizations cannot or will not undertake. Under the envisioned authorities, projects could be privately financed by equitable charges on users.

Without question, however, the Federal Government must continue to take the initiative to set up the needed pollution-control programs, to provide the necessary funds, and to enforce the regulations. The creation of new agencies and the reorganization of the responsibilities of existing agencies are being considered so that Federal action on curbing pollution can move into high gear.

Yet industry's role in responding to pollution control regulations is the key. Industry and the consumers of its products must pay for the use of control methods that will do the job and still not be so costly as to impose undue burdens on the economy. Many corporations, particularly those with increasing social conscience, have shouldered this load and, further, are joining forces with responsible agencies to get us better air quality.

If the control measures are to be really effective, the regulating agencies must have clear-cut authority undiluted by the overlapping or vaguely defined jurisdiction of other government bodies. In the concern over the rising population of rats in our cities, for example, some 10 agencies had a piece of the action, with the result that rats are still a major problem. Further, in a program as vast as the fight against pollution, mutual confidence between industry and government, along with adequate systems for monitoring the air, is essential and must be reflected in the regulating machinery.

Establishing the Standards

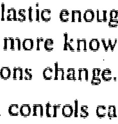
The standards to be achieved in improving environmental quality cannot be rigidly set and enforced like the laws of the Medes and the Persians. For example, very few people expect, or even hope, that congested areas can ever approach the air purity of open country. What is likely to be sought is an environmental quality that is stabilized within the limits appropriate to protecting the health of the population. Beyond that, standards must be determined by the limitations of the nation's economy, by technical

and economic feasibility, and by what the people demand and will pay for.

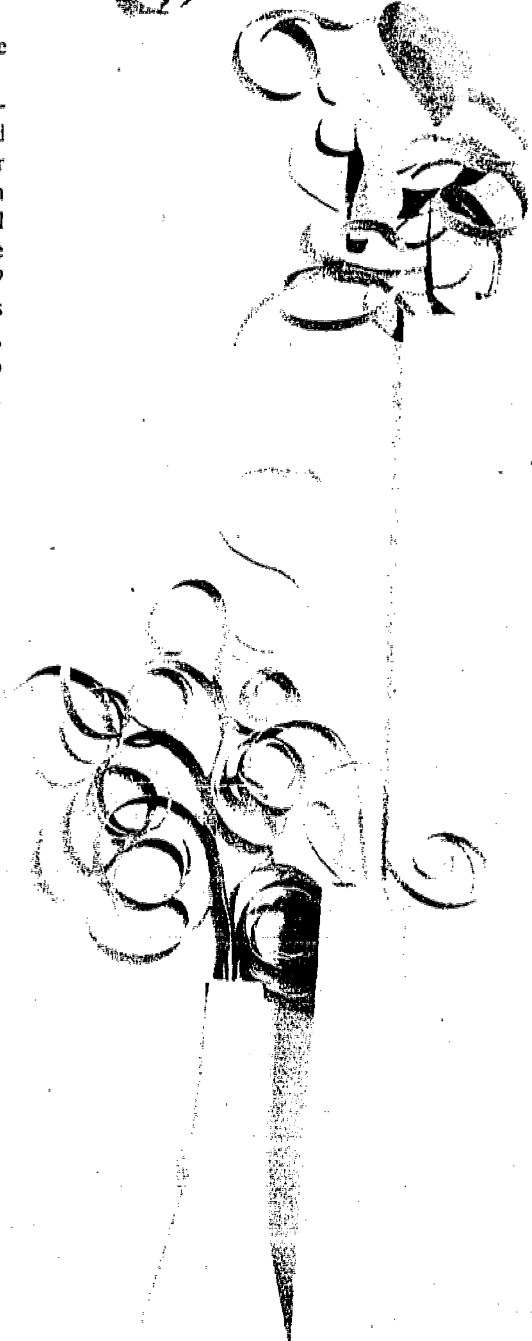
In assessing the impact of these factors, other questions must be answered and other follow-on actions must be taken. For example: How much scientific information is needed to achieve a desired environmental quality? Where is the technology adequate to effect meaningful control programs? Should we set up loosely related programs for air, water, solid wastes, and noise? Or, should such programs be fully integrated to deal more realistically with all pollution issues at once?

At this point, certain matters are clear. Control of pollution will require the following:

- Unified regulatory policies. Such policies



must be clear and understandable so that they can be enforced uniformly.
- Flexible standards. Since the standards that are adopted will depend on available technology as well as on real-life conditions, control standards should be elastic enough to permit easy adjustment as more knowledge is gained and as conditions change.
- Better management. Pollution controls can do the job if new management approaches are developed that assess the consequences of standards-enforcing actions before they are implemented. Methods like systems analysis and cost-effectiveness accounting will make the actions of regulatory agencies more efficient.



- Standardized requirements for comparable types of waste-producing enterprises operating in similar environments. With legal and administrative controls that allow judicious regulation of all companies in the same boat, competitors will have an even break on costs.

Making the Most of Technology

In view of today's forecasts of economic growth and population increase, we have no choice but to make the most of our technology not only in assessing and controlling pollution, but also in managing the attack on the problem. The more stringent the environmental standards, the more important technology becomes. Factors to be considered range from those involving the individual to those relating to political/institutional/aesthetic matters.

If the results of applied research studies are to be useful and timely, high-priority targeted projects must be pushed — hard and fast. Moreover, all research facilities, including those of universities, industries, independent laboratories, and government laboratories, must be put to work. Further development of the sciences underlying the technology and application of the technology that is specific to particular problems call for cooperative effort among these groups and for program objectives that are sharply focused by those who support the research. Those specialists who are oriented to the basic sciences and the "mission oriented" applied scientists must do more and better coordinating.

At the same time, we cannot wait upon the research data still to come. We must make better use of the existing knowledge immediately. The new knowledge that future research will provide will allow us to master the more complex problems that the future is certain to bring.

Assessing Technology's Effects

The basic idea of technological innovation is itself becoming a subject of concern — environmental and otherwise — to many in the U.S. and the world at large. Research brings changes: economic, social, and ecological. How will future research affect our country in the campaign against pollution? More and more citizens are demanding that the government undertake this kind of assessment.

In line with this view, Congressman Emilio Q. Daddario has introduced a bill to set up a technical assessment board. At his instigation, too, the House Science and Astronautics Committee has asked the National Academy of Sciences, the National Academy of Engineering, and the Library of Congress to suggest methods for weighing the benefits and risks of any new technology. The aim of the move is to furnish such assessments as inputs to the processes of legislation and administrative decision-making.

Also, it has been suggested that the government create some type of early warning system that would alert the public to potential technological hazards. Such a system, if based on careful consideration of well-documented evidence, not only would give notice of danger, but also would help put panicky, unwarranted statements into proper perspective.

Viewing the Big Picture

As must be clear now, the significance of air quality is not limited to such simple matters as increasing visibility and eliminating immediate, personal discomfort. Sometimes, the wastes in the environment, even at low concentrations, may be more of a threat than is obvious. No one really knows how airborne chemicals, singly or in combination, affect human life in the long run. New chemicals by the score are being added to the environment each year. The increases in death rate, in medical care required, and in lost working time that are attributed to air pollution add up to a considerable cost to the U.S. economy. In the August 21, 1970 issue of *Science*, Lester B. Lave and Eugene P. Seskin of Carnegie-Mellon University estimated conservatively that a 50 percent decrease in the air pollution levels in major urban areas would reduce this cost by over $2 billion annually — corresponding to 4.5 percent of all economic costs associated with morbidity and mortality.

The time has come, also, when we must consider what pollutants, from cities especially, do to the vegetation in the surrounding region. Los Angeles smog is killing some trees far up the nearby mountains and vegetation around other cities is being stunted or killed off. This kind of attention has to be given also to the effects of chemical fallout upon marine phytoplankton, the tiny ocean plants that supply about 60 percent of our oxygen.

Perhaps a little more remote, but nevertheless a matter that merits study, is the influence of airborne wastes on the ecology of the entire planet. Will the millions of tons of carbon dioxide sent into the air annually create a hothouse effect and thus raise the earth's temperature? Some scientists have cited this possible future danger. On the other hand, will the large volume of particulate matter tend to screen the sunlight and thus cool the earth? We must face this possibility, too.

This emerging era of ecological management will give us the chance to correct our environmental mistakes. But this calls for total waste management — a tall order. We must know quantitatively how much pollution the atmosphere will handle without harming plant and animal life. This means that we must learn more about the atmosphere, how and where it carries wastes, and to what extent it can cleanse itself. We dare not overload it.

To complete the picture, we have to look at man in his total environment. The hazards that concern us often are not single-agent insults. We must assess the impact of contaminants as they come to us not only from the air, but also from the water, the earth, and any combination of these sources.

Given the means and the time, scientists can develop the models that will provide this critical information. A technique that presents this kind of a universal look-see is systems analysis. It will give us a view of the whole — the total ecological system and the effects of demographic, economic, social, physical, and other factors upon it. Systems analysis will permit us to weigh options on the basis of effectiveness, cost, and predicted consequences; to pick the best course open to us; and to move quickly to initiate adequate control measures.

This whole problem, of course, is permeated with human angles. Unless we, the people, face up to the part we play in spoiling the atmosphere, even the best efforts to handle pollution will serve no purpose. Pollution control devices on cars will do no good if car owners don't keep the devices operating. Even such apparently minor matters as wasting electricity or burning trash in open fires can be damaging when multiplied millions of times. Curbing such polluting activities requires lots of publicity, rules and regulations, and enforcement.

It will take herculean efforts to achieve pollution control. No possible source of pollution can be left unguarded, and with more than 3.5 billion people/pollution sources already on earth — a number increasing rapidly — the task is becoming more difficult every day.

PROGNOSIS

For decades, except in unusual cases, we have not been concerned with our environment while pollution sources have proliferated around us. Can we turn this situation around? The prognosis is not promising. Population growth means more electric power, more cars, and more goods. All of these can lead to more effluents, not only in the U.S. but throughout the world.

In the meantime, we have made two important gains. We have become much more aware of the dangers of continued pollution. Further, our technology has reached a point where we can take major steps to control emissions into the atmosphere. We know what we need to do and we have the means of doing it. But will we do it? Commitment to this cause calls for revising our values, adjusting our priorities, and setting realistic goals. Moreover, we face sacrifices in convenience and loss of some personal freedom — the freedom to pollute — as standards tighten and stronger enforcement measures are taken.

Achieving better air quality calls for appropriate legislation, adequate monitoring of the atmosphere, and effective enforcement of the regulations. A socially responsible industry will play a vital role in advancing the technology. But there's no sense in fooling ourselves. Even with the most efficient government activity possible, and with the utmost cooperation from corporations and citizens, the task is formidable. However, in the past, when faced with other major challenges, we have not failed.

AIR QUALITY CONTROL REGIONS

The regions designated and proposed by the National Air Pollution Control Administration are located on the map above and listed below. In most cases, the regions include a considerable area around the locations named.

1 Albuquerque
2 Allentown-Bethlehem-Easton (Penna.)
3 Anchorage
4 Atlanta
5 Augusta (Ga.)/Aiken (S.C.)
6 Baltimore
7 Berlin (N.H.)/Rumford (Me.)
8 Billings
9 Binghamton (N.Y.)/nearby Penna.
10 Birmingham (Ala.)
11 Boise
12 Boston
13 Bristol (Va.)/ Johnson City-Kingsport (Tenn.)
14 Buffalo
15 Burlington (Vt.)
16 Charlotte (N.C.)
17 Chattanooga
18 Cheyenne
19 Chicago
20 Cincinnati
21 Cleveland
22 Columbus (Ga.)/Phenix City (Ala.)
23 Cumberland (Md.)/Keyser (W. Va.)
24 Dallas-Fort Worth
25 Davenport (Ia.)/ Rock Island-Moline (Ill.)
26 Dayton (Ohio)
27 Denver
28 Detroit
29 Douglas (Ariz.)/Lordsburg (N.M.)
30 Dubuque (Ia.)/nearby Ill./nearby Wis.
31 Duluth (Minn.)/Superior (Wis.)
32 El Paso/southeastern N.M.
33 Erie (Penna.)/Ashtabula (Ohio)
34 Evansville (Ind.)/ Owensboro-Henderson (Ky.)
35 Fargo (N.D.)/Moorhead (Minn.)
36 Florence (Ala.)/nearby Miss.
37 Fort Smith (Ark.)/nearby Okla.
38 Hartford
39 Hawaii
40 Houston
41 Huntington (W. Va.)/Ashland (Ky.)/ Portsmouth-Ironton (Ohio)
42 Indianapolis
43 Jacksonville (Fla.)
44 Joplin (Mo.)/Miami (Okla.)
45 Kansas City (Mo. and Kans.)
46 Keokuk (Ia.)/nearby Mo./nearby Ill.
47 LaCrosse (Wis.)/Winona (Minn.)
48 Las Vegas/nearby Ariz.
49 Lawrence-Lowell (Mass.)/ Manchester (N.H.)
50 Lewiston-Moscow (Idaho)/ Clarkston-Pullman (Wash.)
51 Los Angeles
52 Louisville (Ky.)
53 Memphis
54 Menominee-Escanaba (Mich.)/ Marinette (Wis.)
55 Miami
56 Milwaukee
57 Minneapolis-St. Paul
58 Mobile (Ala.)/Pensacola (Fla.)/ Biloxi-Gulfport (Miss.)
59 Monroe (La.)/El Dorado (Ark.)
60 New Orleans and southern La./ southeast Tex.
61 New York
62 Norfolk (Va.)/Elizabeth City (N.C.)
63 Oklahoma City
64 Omaha
65 Paducah (Ky.)/Metropolis (Ill.)
66 Parkersburg (W. Va.)/Marietta (Ohio)
67 Philadelphia
68 Phoenix
69 Pittsburgh
70 Portland (Me.)
71 Portland (Ore.)
72 Providence
73 Puerto Rico
74 Rockford (Ill.)/ Beloit-Janesville (Wis.)
75 St. Louis
76 Salt Lake City
77 San Antonio
78 San Francisco
79 Savannah (Ga.)/Beaufort (S.C.)
80 Seattle-Tacoma
81 Sequatchie River Valley (Ala.)/ nearby Tenn.
82 Shreveport (La.)/Texarkana (Ark.)
83 Sioux City (Ia.)/nearby Neb.
84 Sioux Falls (S.D.)
85 South Bend-Elkhart (Ind.)/ Benton Harbor (Mich.)
86 Spokane (Wash.)/ Coeur d'Alene (Idaho)
87 Steubenville (Ohio)
88 Toledo (Ohio)
89 Vicksburg (Miss.)/Tallulah (La.)
90 Virgin Islands
91 Washington, D.C.
92 Youngstown-Warren (Ohio)/ Sharon (Penna.)

The Regional Approach to Air Quality Control

by Ira L. Whitman and Richard M. Davis

How do you attack this vast problem of air pollution, which blankets much of the nation? Do you meet it head on, and tackle it wherever pollution occurs? While this sounds courageously aggressive, it is an impractical, if not impossible, approach.

Another way to go at the problem is to pick out the really bad areas and deal with them. That is the policy of the National Air Pollution Control Administration (NAPCA), the agency responsible for enforcing the Federal Air Quality Act of 1967 (Public Law 90-148). NAPCA is identifying Air Quality Control Regions that cover the pollution-prone sections of the country. At this writing, more than 90 Regions have been set up or proposed.

THE REGIONAL APPROACH

What are the bases for establishing Regions? NAPCA has listed these:

- *Meteorological and Topographical Factors.* These relate to the atmospheric and physical features in an area that guide air currents and thereby affect the nature and residence time of air pollution conditions. Los Angeles is a prime example of what these factors can do to air quality.
- *Urban and Industrial Concentrations.* Each Region has a highly populated area and characteristic economic and social patterns that affect air quality. Significant factors include types of manufacturing and businesses, which are frequent sources of pollution; distribution of these activities within the region; and location of working populations along with commuting zones.
- *Jurisdictional Boundaries.* Air Quality Control Regions are associated with certain political units — cities, counties, or states — that can serve as bases for regional administration. Any other factors that are relevant to air quality standards are also considered.

The Air Quality Act distributes responsibilities over all three levels of government — Federal, state, and local. However, the task of creating and implementing the regional administrative machinery rests upon the states. NAPCA designates the Regions and is chartered to develop and support their information facilities. Further, NAPCA must agree to the air quality standards that the states set, as well as state plans for administering the standards, before the Regions can begin to operate.

In some areas identified as Regions, suitable control agencies already are in business. In other Regions, existing agencies, perhaps city or county health departments, lack the necessary broad authority or acceptance. There, those charged with setting up the required administrative machinery face the rigors of forming agencies that can enforce the regulations while still satisfying the political and jurisdictional sensitivities of competing local governments.

Political problems are likely to be even stickier when two or more states are involved in organizing a Region. An international flavor is added when, as along the St. Clair River, Canadian communities like Windsor lay plans to join forces with Regions in Michigan. The history of metropolitan government in the U.S. suggests that mixing county, municipal, township, and other local entities may gain more opponents than supporters for Regions set up in some areas. When that happens, pollution control will take a licking unless the states and NAPCA can exercise enough muscle to overcome local ineffectiveness.

BENEFITS OF THE REGIONAL APPROACH

The regional approach, as envisioned by NAPCA, presents many opportunities for combining city and regional planning that can lead to real improvement in the quality of life in metropolitan areas. At the same time, it lays the foundation for the advancement and interplay of the various technologies that can contribute so much to bettering the environmental quality.

Regional Planning

Quality of the environment — particularly of the atmosphere — is becoming a critical factor in metropolitan planning for living/working space. Further, as Battelle-Columbus environmental specialists have found in their contacts with local planners, regional, rather than just municipal, approaches to environmental problems are preferred more and more.

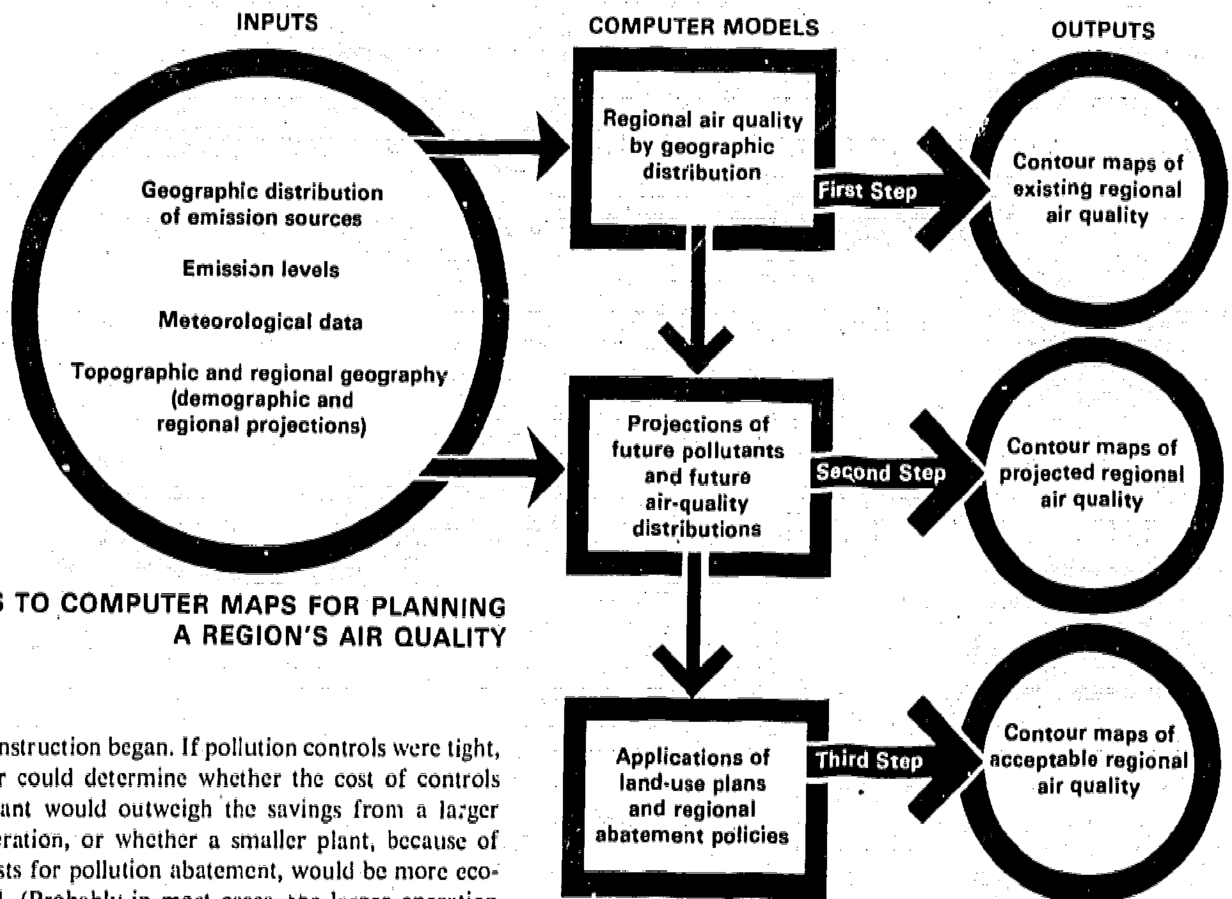
Land-use planning for the future must be built upon considerations of environmental quality as well as the spatial, topographic, climatic, economic, and social characteristics of a region. The resulting plans then will show the way for locating expanding industry, transportation, and other economic activities, and will determine residential patterns. While traditionally the reduction of air pollution leans upon controlling processes and modifying energy sources, the approach outlined here extends air quality improvement into zoning and other land-use specifications. Such a strategy will allow the region's natural features to be developed maximally while keeping the air quality high in areas where people live and congregate.

Air quality can be protected by judiciously situating the sources of pollution. Planners frequently work backward in this regard. First they set standards of atmospheric quality. Then they compute the types and volume of pollutants that the various sectors in the area can tolerate while meeting the quality standards. Pollution sources can be arranged in different ways, to meet varying requirements. For example, planners might concentrate emitters of similar pollutants in one location, or focus a spectrum of emissions by grouping plants that share power and other facilities, as in industrial parks.

The regional planners compare their land-use schemes in the light of factors that will influence future economic devel-

appears to deal most effectively with all the factors involved. But the plan is seldom accepted *in toto*. Too often it is seriously compromised or even turned down. Hopefully, as air pollution gains more stature as a vital element in such schemes, the value of such integrated planning will be generally recognized, and communities will benefit more fully from the skills of the planners they employ.

With a plan accepted, zoning classifications can be issued that specify not only how the land may be used (for commercial or industrial purposes, for example), but also the permissible levels of emissions. The benefits to the businessman are obvious: the zoning allowances would enable him to figure costs before plant construction began. If pollution controls were tight, a manufacturer could determine whether the cost of controls for a larger plant would outweigh the savings from a larger production operation, or whether a smaller plant, because of the reduced costs for pollution abatement, would be more economical overall. (Probably in most cases, the larger operation would still be more profitable.)



STEPS TO COMPUTER MAPS FOR PLANNING A REGION'S AIR QUALITY

Interdisciplinary Technology

Regional air-quality planning takes a combination of technical skills that is rarely available to local government agencies other than those in large cities or regions. Putting all the pieces together is the key task of the regional agencies.

In dealing with air quality, as with environmental quality generally, the focus is on the future. Useful research results obtained today may lead to improvements anywhere from a few years to decades from now. This being true, regional planning must take into account the factors that can influence air quality at some future date. But the only data on hand are those from yesterday and today. This is where demographers, economists, and other social scientists come in.

Demographic studies can provide some figure for a region's population at some future date. Since people must earn a living, such a figure can lead to a rough estimate of future economic activity. Economists can forecast the probable types and sizes of industries. From these estimates, technologists can gage future pollution emissions and their levels.

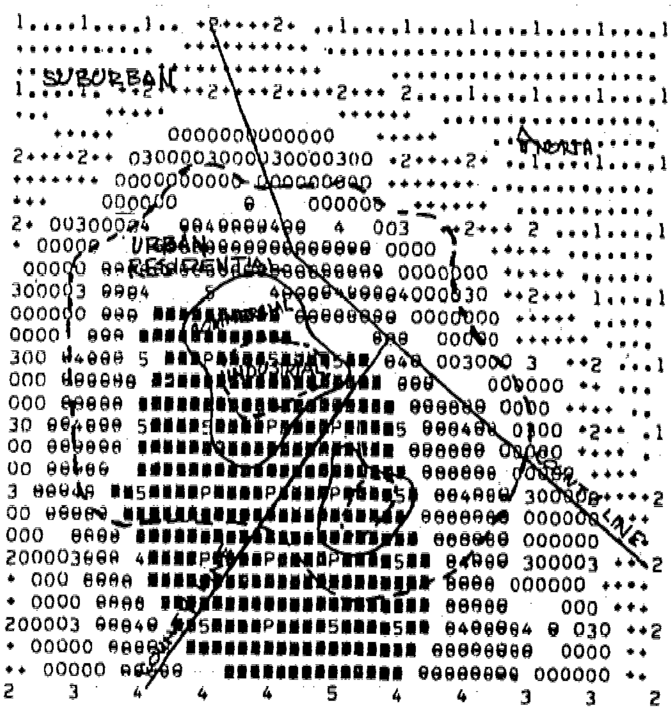
Along this line, Battelle-Columbus economists and demographers are working out economic and population projections to the year 2020 for two Ohio regions, in connection with water studies. Models project population figures on the basis of demographic variables and relate the population changes to employment. It appears quite feasible to use similar models and appropriate data to forecast the effects of such changes upon environmental quality.

Pulling together the information needed to project conditions that will influence pollution in the future demands an experienced team. Meteorologists, chemists, specialists in fluid (gas) mechanics, biologists, and others, in addition to economists and demographers, handle the scientific aspects. The technological problems require specialists in such fields as manufacturing, power sources (ranging from cars to power plants), transportation, and incineration and waste disposal. On occasion, photogrammetrists, health technologists, microscopists, chemical analysts, and others join the team.

Once emissions are projected, the team estimates the corresponding air quality. This sort of estimating, now done

with computerized models, enables agencies to assess also the geographical distribution of contaminants over a long term. With systems analysis techniques, land-use plans can be developed for further economic growth in a particular region, and regional policies can be set for abating air pollution at minimum cost.

Mapping is one of the mainstays of regional planning. Features that have influenced the development and growth of the area, and those likely to be significant in the future, are basic here. They generally are mapped individually and combined, to form a basis for designing future land-use plans. The computer can then produce excellent regional maps of air quality for some desired period, according to a given land-use plan, and based on various types of pollutants and their possible effects upon the environment and the people. Because such maps



Computer Maps. The colored patterns show how data are reproduced on computer-printed maps. Such maps are scaled to a geographical grid based on topographic and other maps, and they are read against the grid used as an underlay. Here, base-map information is sketched on the computer map itself. Computer maps are easy to update, and they can be printed at minimum cost, as needed.

are scaled to fit the basic geographic grid pattern, they are congruent with conventional land-use, topographic, population, and other maps used in analyzing the region. The sequence of computational mapping is outlined in the chart.

Computer maps are particularly useful when a large number of maps are employed one at a time or when maps of a particular area are needed for various time periods. Since they cost less than hand drawn maps, the analyst can call for the computer maps he needs in solving a problem and then dispose of them when he has finished.

Because the regional planner is trained to understand problems related to the interactions among social, economic, political, and technical factors, he is also a key to regional air-quality planning. Adding air pollution control to the other major elements in regional planning merely increases the need for experienced regional planners and for the technical specialists that pollution abatement requires.

ZEROING IN ON AIR POLLUTION

The nature and scope of the pollution problems besetting the different Air Quality Control Regions vary tremendously. The situations in New York or Los Angeles are much more complicated than, say, in Boise or Honolulu. Yet the approaches to be taken in attacking the problems will be broadly the same.

Working out a program for a community to use in managing its air quality involves four basic phases: inventory, development, evaluation, and implementation.

The inventory phase characterizes all elements of the community that relate to air pollution. This means establishing the socioeconomic base of life in the area — how the people earn their living, who lives where, and the like. The area's meteorology and variations in its air chemistry are studied. The legal and institutional base of pollution control is determined, and the effects of pollutants on the health and economic life of the inhabitants and on the area's aesthetics are examined.

The development phase builds on such information. The air quality of the area is modeled. The next step entails projecting the area's economic development, and creating alternative plans and strategies for achieving optimum air quality in the near and distant futures.

The evaluation phase follows. The alternative land-use plans and air-management strategies are analyzed, and the merits of each are rated.

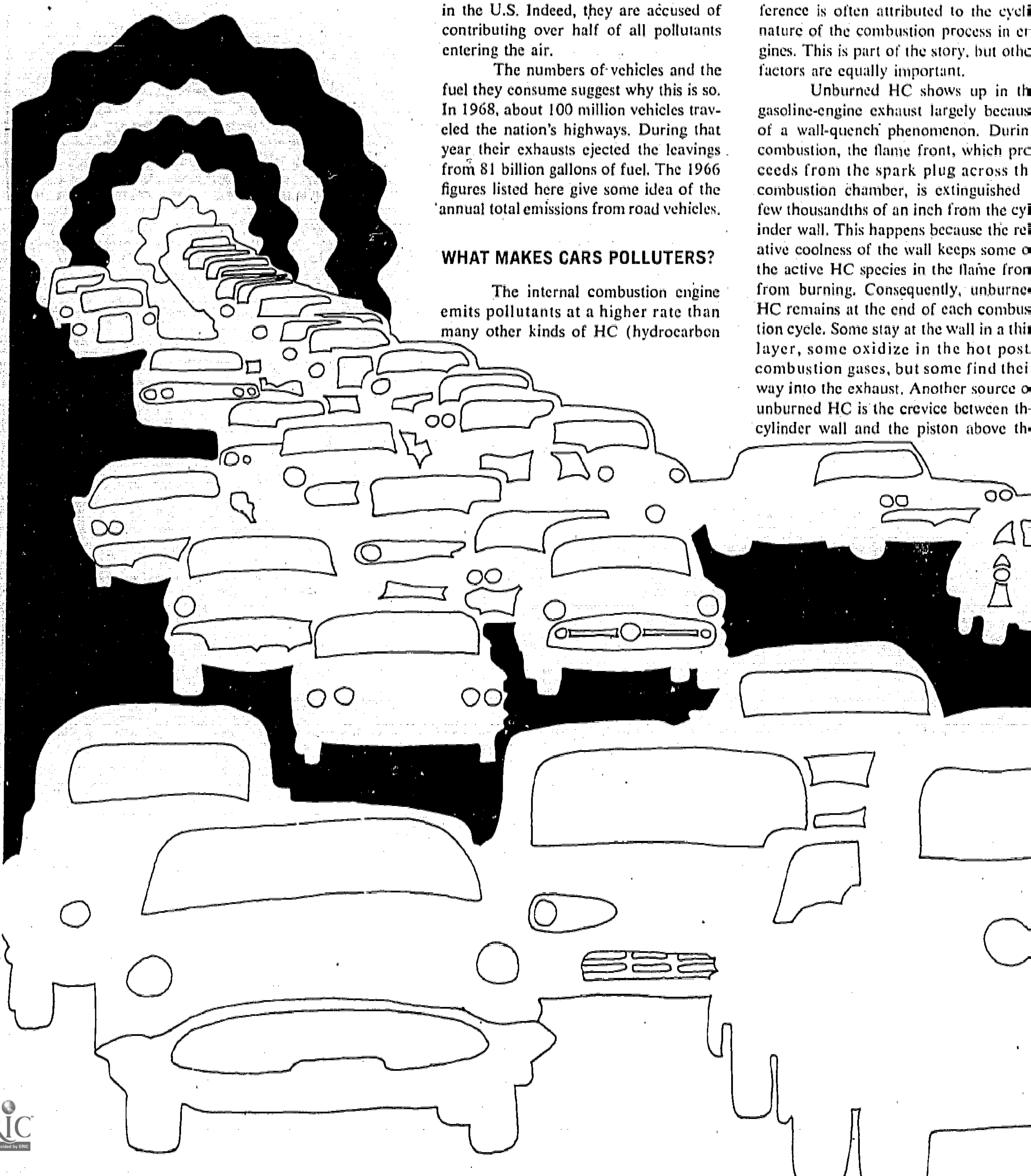
The implementation phase — the ball must eventually be placed in the community's hands. The community, through its elected officials and governmental processes, is called upon to select the plan it deems best and then to establish the machinery to carry it out.

A study that typifies this regional approach is being performed by Battelle's environmental-planning specialists in cooperation with the Dayton (Ohio) Air Quality Control Region. The basic data have been inventoried for the Region, which comprises 6 counties, including 2 sizeable industrial cities — Dayton and Springfield; several smaller population centers that range from one-industry towns to farm villages; and farmland. All of this area shares economic ties as well as sources of pollution. Using available emission data, the research team has successfully modeled the air quality of the Region. The resulting computer maps are now being employed to evaluate the impacts of various land-use plans and of major industrial sites on the Region's air quality levels.

Obviously, the attack on pollution must be many-sided and long term. Amassing, processing, digesting, and analyzing the information from yesterday and today constitute a time-consuming, exacting task; it calls for fusing the efforts of practitioners in many disciplines. The regional approach offers the greatest promise for overcoming the air pollution problem. Successful implementation requires good management, which the Air Quality Control Regions must provide; adequate funding; and a team of knowledgeable and experienced technologists. Today's research is tailored to generate the kinds of information and know-how that are vital to the success of this approach.

AIR POLLUTION FROM MOTOR VEHICLES

by David A. Trayser and Frederick A. Creswick



VEHICLES POWERED by internal combustion engines have been identified as the greatest single source of air pollution in the U.S. Indeed, they are accused of contributing over half of all pollutants entering the air.

The numbers of vehicles and the fuel they consume suggest why this is so. In 1968, about 100 million vehicles traveled the nation's highways. During that year their exhausts ejected the leavings from 81 billion gallons of fuel. The 1966 figures listed here give some idea of the annual total emissions from road vehicles.

WHAT MAKES CARS POLLUTERS?

The internal combustion engine emits pollutants at a higher rate than many other kinds of HC (hydrocarbon — or RH in chemist's notation) energ converters. Home oil furnaces, for ex- ample, are less serious polluters. The di ference is often attributed to the cycli nature of the combustion process in en gines. This is part of the story, but othe factors are equally important.

Unburned HC shows up in th gasoline-engine exhaust largely becaus of a wall-quench phenomenon. Durin combustion, the flame front, which pro ceeds from the spark plug across th combustion chamber, is extinguished few thousandths of an inch from the cyl inder wall. This happens because the rel ative coolness of the wall keeps some o the active HC species in the flame fron from burning. Consequently, unburned HC remains at the end of each combus tion cycle. Some stay at the wall in a thin layer, some oxidize in the hot post combustion gases, but some find thei way into the exhaust. Another source o unburned HC is the crevice between th cylinder wall and the piston above th

TOTAL EMISSIONS OF MOTOR VEHICLES IN THE U.S. IN 1966

Pollutant	Tons	% of Emissions From All Combustion Processes
Carbon monoxide (CO)	62,100,000	70
Hydrocarbons (HC)	16,400,000	60
Nitrogen oxides (NO_x)	6,300,000	33
Lead particulates	210,000	100
Other particulates	400,000	2

first ring. Air/fuel mixture forced into this pocket during compression does not burn and is subsequently released during the expansion stroke.

Oxides of nitrogen result to a great extent from the high cylinder pressure and high peak combustion temperature that are typical of the internal combustion engine. The nitrogen and oxygen in the intake air combine rapidly to form NO at temperatures above 2500 F. Unfortunately, the reverse reaction is much slower, and little of the NO breaks down in the course of the rapid cooling that occurs during the power and exhaust strokes, as the gases expand and escape. Consequently, the amounts of NO found in engine exhaust correspond closely to equilibrium concentrations that can be predicted for the peak combustion temperature.

Carbon monoxide is perhaps more closely tied to the cyclic nature of the combustion process than the other exhaust emissions. A fairly large amount of CO is an equilibrium component of the products of combustion at high temperatures, but very little CO would be expected at the relatively low exhaust temperatures (with balanced or leaner mixtures). In time, nearly all of the CO could convert to CO_2 at the temperatures occurring between combustion and exhaust; but again, rapid cooling of the combustion products prevents this.

The exhaust is not the only source of emissions. Gases from the crankcase and fuel vapors from the tank and carburetor also count. The crankcase gases—which could comprise 25 percent of the engine's HC emissions if not controlled — come from "blowby" of partially unburned fuel and combustion gases that escape past the piston rings. Fuel evaporating from the tank and carburetor float bowl can supply another 15 percent of the emissions. The vapors are caused by expansion and contraction of the fuel as the outside temperature changes (diurnal breathing); heat from the running engine; and hot soak evaporation (as heat from the stopped engine moves to parts that are cooled while the engine runs).

SETTING EMISSION LIMITS

California's standards for exhaust emissions became effective in 1965 (with 1966 models) when control devices were first able to meet performance, durability, and cost requirements. Limits of 275 ppm (parts per million) of HC and 1.5 percent by volume of CO were set.

For the 1970 cars, both California and Federal standards were tightened; only 180 ppm of HC and 1 percent of CO were allowed for a standard-size (4,000 lb) car. Further planned decreases are listed here. As indicated, pollutants are

TIGHTENING POLLUTION STANDARDS

Car Model Year	Permissible Rate of Emission, grams/mile—2¼ m test HC	CO	NO_x
	California/Federal Standards		
1970	2.2	23.0	–
	California Pure Air Act, 1968		
1971	2.2	23.0	4.0
1972	1.5	23.0	3.0
1974	1.5	23.0	1.3
	Proposed Federal Standards		
1975	0.5	11.0	0.9
1980	0.25	9.7	0.4

Note: New proposed Federal limits for 1972 cars, based on new 22-minute test, are 3.4 gm/mile HC and 39 gm/mile CO.

now expressed on a basis of grams per mile rather than parts per million or percent. This is a more realistic way of assessing the true polluting potential of an engine, and also it compensates for differences in size. In effect, the larger the engine, the cleaner its exhaust must be. As an approximation: for a standard auto, 1 gm/mile of HC is equivalent to 79 ppm; 10 gm/mile of CO, to 4,300 ppm; and 1 gm/mile of NO_x, to 250 ppm. The Federal Government also plans to limit particulates (lead, carbon, and other elements) to 0.1 gm/mile in 1975, and Congress recently passed legislation to bring the proposed 1980 standards for HC, CO, and NO_x forward to 1975.

Evaluating these emissions calls for "driving" the car on a chassis dynamometer. This device absorbs power from the car's rear wheels and imposes inertia loads during speed changes through a 2¼-minute prescribed driving pattern of accelerating, decelerating, idling, and steady cruising, referred to as the 7-mode driving cycle. HC, CO, and CO_2 emissions are continuously measured and recorded during 7 consecutive cycles, and HC and CO emissions, adjusted by dilution and weighting factors, are summed up to yield total composite values for each pollutant.

Recognizing some shortcomings in this evaluation method, the Federal Government is considering changes in both the driving cycle and the method of sampling the exhaust. The proposed cycle, designated the DHEW Urban Dynamometer Driving Schedule, covers almost 22 minutes of continuous driving and is intended to simulate an average 7½-mile trip in an urban area. The proposed exhaust-sampling procedure is simplified and, further, it collects a truly composite sample over the whole driving cycle with higher gm/mile readings. The changes may apply to 1972 models.

The following suggests what typical autos emit in the course of meeting 1970 standards. At the CO limit of 23 gm/mile, about 0.01 pound of CO emerges per pound of exhaust. Since 15 pounds of air are needed to burn 1 pound of gasoline — totaling 16 pounds of exhaust — each pound of gasoline produces 0.16 pound of CO. At this rate, the 81 billion gallons of gasoline burned in 1968 produced about 39 million tons of CO. Even with present emission standards, which, of course, most cars now on the road cannot attain, CO and other pollutants still pose a massive problem.

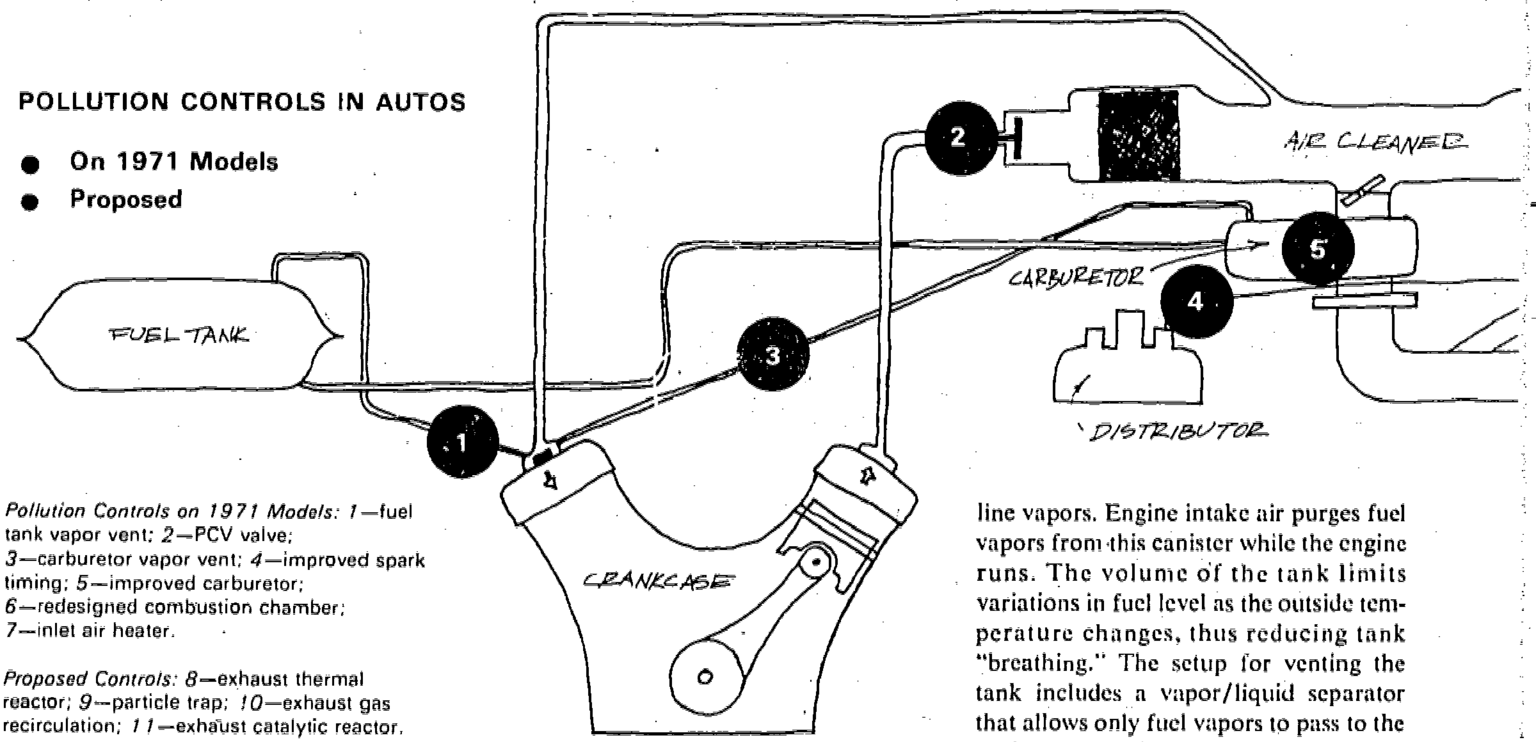
TODAY'S CONTROL MEASURES

Before automotive pollution was regulated, the characteristics of the emissions had no significance in the marketplace, so they were generally ignored. Auto engines were designed for qualities like high maximum-power-to-weight ratio, praiseworthy gas mileage, reliable starting, and good "driveability" — a term used to describe fast response, smoothness, and other sensations prized by the driver.

In recent years, of course, the aim of automotive engineers has changed to meeting emission standards while compromising other desirable features as little as possible. No one knows how clean the gasoline engine can ultimately be made by reoptimizing the engineering variables. Further, revising the engine design is only one approach to abating automotive air pollution. As the campaign to reduce polluting emissions has pushed ahead, a number of control methods have evolved, several of which are now standard.

Crankcase Blowby Control

This was the first step. Crankcase blowby control was installed in all U.S.



Pollution Controls on 1971 Models: 1—fuel tank vapor vent; *2*—PCV valve; *3*—carburetor vapor vent; *4*—improved spark timing; *5*—improved carburetor; *6*—redesigned combustion chamber; *7*—inlet air heater.

Proposed Controls: 8—exhaust thermal reactor; *9*—particle trap; *10*—exhaust gas recirculation; *11*—exhaust catalytic reactor.

cars beginning with the 1965 model. PCV (positive crankcase ventilation), as it is called, replaced the "breather" to the atmosphere with a tube to carry the crankcase blowby gases back into the engine through the intake system. Since this produced a vacuum in the crankcase during engine operation, an inlet with a filter was also provided to bring in fresh air to ventilate the crankcase. A valve (the PCV valve) in the blowby tube keeps the flow of blowby gases adjusted to the flow of air/fuel mixture to the engine, thus maintaining normal operation and preventing backfire into the crankcase.

Exhaust Emission Control

Exhaust emissions were harder to limit. But two methods were ready for all 1968 models sold in the U.S.

Chrysler's approach called for four engine modifications: (1) changing the carburetor idle adjustments and fuel jets, (2) recalibrating the choke control for faster opening during engine warm-up, (3) altering the distributor spark-advance schedule, and (4) adding a distributor vacuum-control valve. These led to leaner air/fuel ratios during idle and low-speed cruise, retarded spark timing to facilitate ignition and burning of these leaner mixtures, advanced spark timing during closed throttle deceleration to lengthen combustion time, and leaner mixture operation during engine warm-up — a combination that curtailed exhaust emissions effectively.

General Motors, Ford, and American Motors initially used an [engi]ne-driven pump to deliver air to each [exha]ust passage near the exhaust valve. The exhaust gases are still hot enough at this point to allow burning to continue in the exhaust system. The air injection approach also includes modifying the distributor spark-advance schedule (to retard the spark at idle and low speed), increasing the idle speed setting, and adding an intake-manifold relief valve that opens momentarily during rapid throttle closures to prevent backfire into the manifold during deceleration.

Since the introduction of these exhaust controls, improvements in the control systems and in engine design have further reduced emissions and increased the control systems' reliability. Among these improvements are: tighter control over manufacturing tolerances in carburetors, redesign of combustion chambers to minimize surface-to-volume ratio and to eliminate crevices, preheating of the intake air to increase the fuel-metering accuracy and to distribute the mixture better, and control of spark timing by the transmission so that the spark is retarded unless the engine is in high gear. At present, most systems for abating exhaust emissions in new cars emphasize engine modification rather than exhaust treatment.

Evaporative Emission Control

Controls on evaporative emissions were required on 1970 model cars sold in California. They are now mandatory on all 1971 models marketed in the U.S.

A typical system for limiting these emissions vents the fuel tank and carburetor float bowl through a canister of activated carbon, which traps the gasoline vapors. Engine intake air purges fuel vapors from this canister while the engine runs. The volume of the tank limits variations in fuel level as the outside temperature changes, thus reducing tank "breathing." The setup for venting the tank includes a vapor/liquid separator that allows only fuel vapors to pass to the canister (returning the liquid fuel to the tank), and a pressure/vacuum relief valve that prevents a buildup of excessive pressure or vacuum in the tank.

These various control measures appear to be worth the effort. Some people have estimated that for 1971 cars, HC emissions are about 80 percent less, and CO emissions about 70 percent less, than for pre-1968 cars. Whether or not these estimates are reasonable, there is ample evidence that pollutants can be reduced some more without abandoning the present internal combustion engine.

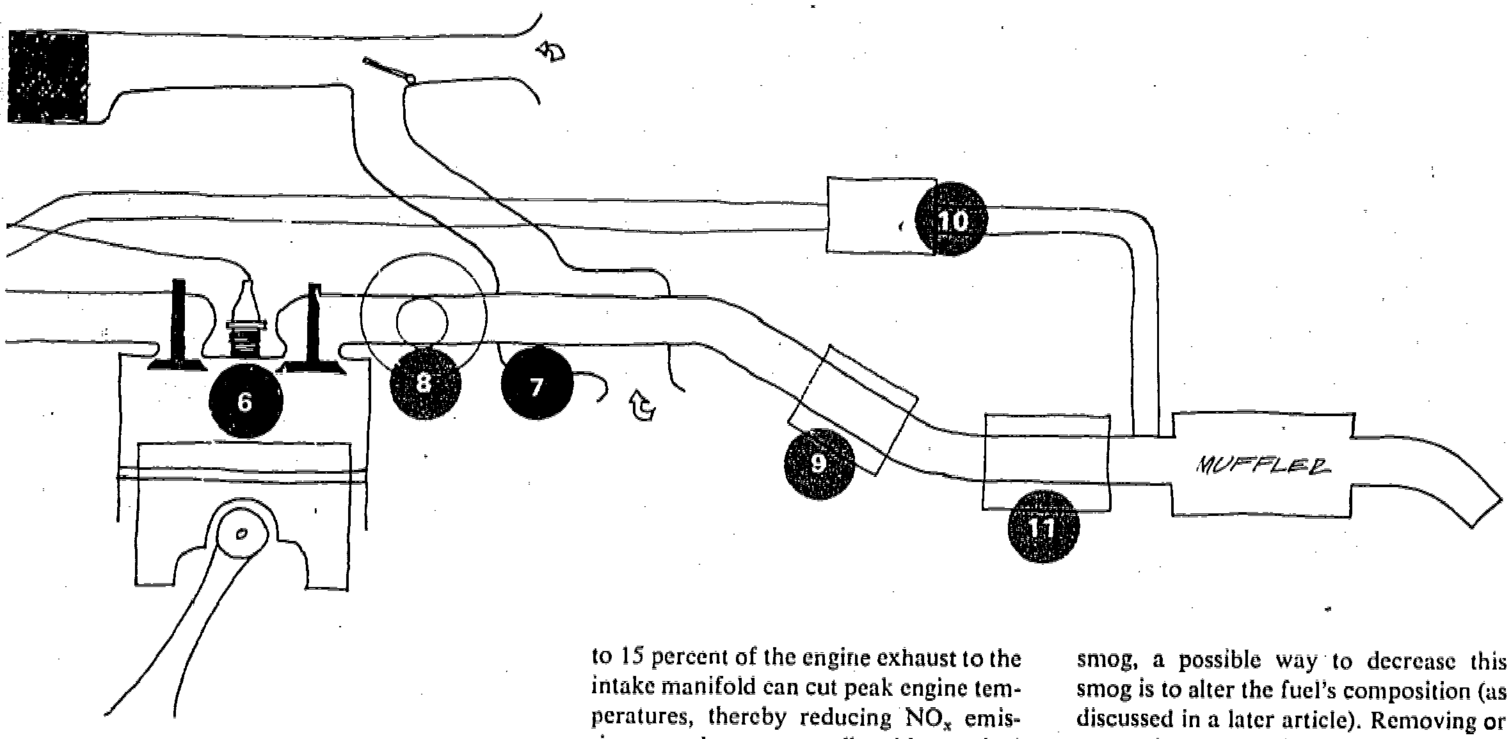
CLEANER YET TOMORROW

Basically, there are three ways to clean up today's car engines further: (1) more engine modifications, (2) added treatment of the after-engine exhaust, and (3) fuel changes. All are possible, although the time frame for each is a little different. Another possibility — using other power plants — is discussed later.

Modifying the Engine

It is likely that most improvements that can be made by optimizing conventional engine designs have been assessed by the auto producers, and that the knowledge so obtained will be used in future designs, given the right incentives. However, certain engine-modification approaches need more study.

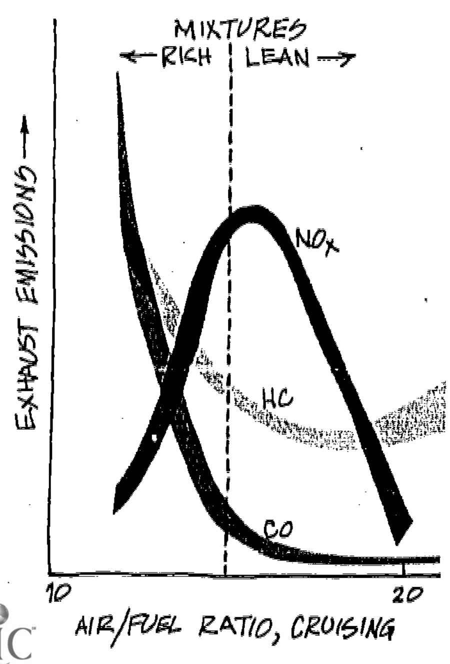
One approach involves lean mixture operation. As shown here in the graph, emissions vary with the air/fuel mixture ratio under constant operating conditions. With very lean mixture ratios



(20 to 1 or leaner), NO_x emissions drop sharply while HC and CO emissions stay fairly close to their minimum values. Present engines tend to "surge" and accelerate poorly on such lean ratios. A much better induction system (carburetor and intake manifold) is needed to distribute the fuel more evenly. In studying this problem, Battelle-Columbus engineers have analyzed droplet dynamics and vaporization as related to droplet size and to manifold geometry and operating conditions. Current effort is focused on experimentally investigating the transport of fuel droplets in an air stream and the benefits of improved fuel atomization.

Another kind of engine modification that holds promise relates to exhaust gas recirculation. Devices that return up to 15 percent of the engine exhaust to the intake manifold can cut peak engine temperatures, thereby reducing NO_x emissions greatly — reportedly with marginal sacrifice in driveability and fuel economy. Though it is still being evaluated, exhaust gas recirculation seems to have the inside track for reducing NO_x to levels set for the next few years.

The stratified-charge engine, also under study now, offers a different approach. By using in-cylinder fuel injection and controlled air-charge motion, combustion is confined to one portion of the combustion chamber, with only excess air in the rest of the cylinder. The emission levels of some engines that operate this way are promising. While such engines were developed in the past for their potentially excellent, part-load fuel economy, manufacturing cost may be too high to encourage general automotive use.



Treating the Exhaust

In the 1970 to 1980 time frame, two after-engine exhaust devices give hope for dropping the HC and CO levels. Exhaust-manifold reactors work by mixing exhaust gases with high temperature air to oxidize the HC and CO. Catalytic reactors oxidize these pollutants in a catalyst bed. Both devices are effective, though so far they are not durable enough and they do not remove NO_x. Moreover, variations in engine-exhaust temperature and composition complicate their design; also, lead compounds in gasoline work against the catalytic approach.

Changing the Fuel

Since hydrocarbons vary in their potential for making photochemical smog, a possible way to decrease this smog is to alter the fuel's composition (as discussed in a later article). Removing or decreasing the light olefin content of gasoline, for instance, makes the exhaust less reactive with the atmosphere. However, since this change reduces the fuel's octane rating and volatility, other composition changes would be needed to compensate for these effects. Obviously, modifying the composition of today's gasoline is not a simple approach.

The use of natural gas (mostly methane) as an automotive fuel has interesting possibilities. Since methane is nonreactive photochemically, there is some justification for disregarding it in auto exhaust. By running with lean mixtures — which natural gas seems to tolerate well — emission levels (ignoring methane) can be kept low. In addition, fuel costs are favorable, and a wealth of operating experience (seemingly overlooked in the U.S.) is available from the 50,000 small cars that have been run in northern Italy on compressed natural gas.

But the related problems are serious. Vehicles using tanks of compressed natural gas are limited to short trips between fuel stops. The use of liquid natural gas could extend the range, but cryogenic storage tanks are costly and suffer boil-off losses during idle periods. Still larger difficulties would face any attempt to furnish liquid natural gas for even a fraction of the huge number of autos in the U.S., to find adequate supplies of gas for the future, and to convert the gasoline-producing capacity of the petroleum industry over to different products.

Other fuels have been proposed: hydrogen, methanol, liquified petroleum gas (LPG), and ammonia. Each has a supply, performance, tankage, or cost problem. So far, it is not clear that any

of those fuels offers either short-term or long-term relief on a national scale.

ALTERNATIVE POWER PLANTS

Let's look at the possibility of relieving auto emissions by replacing the internal combustion engine with a different power source.

Two years ago, Battelle-Columbus examined this possibility for the National Air Pollution Control Administration by determining what types of power plants might be suitable for automotive use with low pollution potential, and also what related R & D tasks were justifiable. The investigators concluded that practical versions of promising alternatives are not available and that it would take extensive research to exploit even the most promising ones.

Electric Vehicles

Pollution-free electric vehicles serve specific purposes today; trolley buses, lift trucks, and golf carts are examples. Why, then, no electric autos?

Perhaps the main reason is lack of a practical storage battery that would deliver enough energy for a useful period of service. Conventional batteries such as the lead-acid, nickel-cadmium, or silver-zinc types won't do it with a weight and volume that are reasonable for a family car. Also, some of these are extremely costly. Even experimental high-energy-density systems, like lithium-chlorine, sodium-sulfur, and zinc-air, look good only for vehicles such as cars used for commuting (in contrast with ranging over the country-wide highways). Electric cars pose another problem. Their use only transfers the source of the pollutants from the vehicles to the generating station. Of course, the modern station might be cleaned up more readily than the conventional engine.

Although the immediate future doesn't look bright for the electrics, they must be considered as a possibility one day. New vehicular concepts and different modes of usage in the future could modify this situation; certainly any major advance in the storage of electric energy could change the picture completely.

Steam Engines

There's little doubt that steam can be used to drive autos, since Stanley Steamers ran successfully early in the century. Today, recognizing that other fluids can also handle this task, we call this breed of power plant a Rankine-cycle engine. Although the old steamers worked, they would hardly be practical today. The main problem: freezing. In cold weather they had to be drained or left steaming. Despite recent talk about trying an antifreeze in the system, no one has yet demonstrated a way around freezing in Rankine-cycle engines with water as the working fluid. Any antifreeze used would have to go through the boiler; no suitable compounds have been identified that would survive at or near 1000 F, the typical steam-boiler temperature.

Working fluids that will not freeze in normal winter weather are being examined. Thiophene (C_4H_4S) and perfluoro cyclic ether ($C_8F_{16}O$) are examples. Both have been tried in experimental engines with some success. Generally, these organic fluids are used with peak cycle temperatures of 500 to 700 F; cycle efficiencies are a little low compared to the internal combustion engine, but not unreasonably so. Although progress with organic fluid systems is encouraging, there are problems: many of these fluids are flammable, are somewhat toxic, and often have an objectionable odor. Some, such as the fully fluorinated hydrocarbons, may be nonflammable and nontoxic, but they tend to be expensive — \$5 to \$10 per pound. Others, such as hexafluorobenzene (C_6F_6), look like they have favorable thermodynamic characteristics, but they haven't yet been made in commercial amounts.

The Rankine-cycle engine in its present state has several other drawbacks. The condenser must reject 3 to 4 times the heat handled by today's auto radiator. The combustion system must perform with low emissions over a range of fuel flow that can vary by a factor of 50 or more. The actions of several individual system components must be intricately matched by the control system. Lubrication is not easy, especially with steam systems. Simple, reliable, low-cost solutions to these problems are yet to be worked out. Finally, there's the difficulty of getting the power plant under the hood of conventional autos.

Available continuous-combustion systems have been operated over a narrow range of firing rates with low emissions. However, present technology and equipment cannot provide a low-emission combustion system that has the extremely wide turndown range needed for automotive use. Battelle-Columbus has a program under way to develop an experimental combustion system for a Rankine-cycle automotive engine that will meet proposed 1980 emission standards while working over a firing rate range of 100 to 1 (maximum power to idle).

Although many of the drawbacks of the Rankine-cycle engine appear discouraging, the incentives to continue development work are strong. A continuously burning external combustor offers great hope for minimizing emissions from the combustion process itself. Improvement in emission levels over 1970 production engines could amount to one order of magnitude and possibly two. Right now, the incentives look as big as the problems.

Gas Turbines

Turbines are one of the more promising alternative power plants for road vehicles. Early evidence of their potential came from an evaluation made by an auto company in the early 1960's. Fifty turbine-powered autos were lent to individuals, each of whom ran the vehicle for 3 months. Although the full results of this program never came out, there seemed to be little doubt that the turbine was generally satisfactory. Nevertheless, no plans for producing turbine-powered autos have been reported. However, two U.S. manufacturers plan to market heavy-duty turbine engines for trucks in the mid-1970's.

Cost probably has been the main deterrent to using turbines for autos so far. Even if this factor can be resolved, there is no clear incentive for the industry to switch to turbines. Although their HC and CO emissions are quite low, reducing the typically high NO_x emissions looms as a very difficult task.

A FORWARD LOOK

Since no clearly acceptable, unconventional power plant is available, and all of those that are potentially acceptable require the solution of some tough development problems, the internal combustion engine is unlikely to be dethroned in the next decade. Beyond that, there doesn't seem to be a sound basis for making predictions. One point seems fairly certain, however: the auto industry will be extremely reluctant to switch to an alternative power plant as a short-term or temporary expedient for cutting down auto emissions. When and if a change is made, that new power plant will probably appear to be the best solution for several decades to come.

Solving the Riddle of Smog

by Arthur Levy, William E. Wilson, Jr., and Salo E. Miller

SMOG — the word was invented to describe a mixture of smoke and fog. But the meanings of words change, and smog has changed, too. The infamous smog of Pittsburgh, London, and many cities in the early 1900's is not what is irritating eyes, shriveling plant life, and hazing skies today. That sooty fog was cleaned up. But some kind of smog still plagues cities like Los Angeles, Denver, Washington, D. C., and on and on. What's happened?

Today's smog is a subtle and insidious creation called *photochemical smog*. For many years, before anyone knew much about it, we heard of "Los Angeles smog." It was known vaguely to have something to do with the many automobiles, the ubiquitous sunshine, and the boxed-in terrain that characterized Los Angeles. However, the real nature of photochemical smog was not pinned down until A. J. Haagen-Smit published his pioneering work in 1951. He proved that atmospheric hydrocarbons and nitrogen oxides, mainly from auto exhausts, were reacting under the influence of sunlight to create the Los Angeles smog.

This photochemical smog is sneaky stuff; its damaging effects are often invisible and indirect. The basic components, the hydrocarbons and nitrogen oxides, are neither visible nor particularly harmful to man or his surroundings in the amounts that are found in the air. However, when sunlight gets to work on them, the results — ozone, aerosol formers, aldehydes, organic peroxides, nitrates, etc. — even if not downright hazardous, are irritating and expensive nuisances.

THE CHEMISTRY OF SMOG

In its simplest form, the chemical smog equation can be expressed as:

$$RH + NO_x \xrightarrow{\text{sunlight}} \text{smog}.$$

This says that when a mixture of hydrocarbons (and organic compounds in general) and nitrogen oxides is exposed to sunlight, smog results. The equation, however, greatly oversimplifies a complex process. The variety of hydrocarbons involved and the number of reaction products formed are legion, and many aspects of the reactions that occur are understood only vaguely, if at all. But, we do know the most common kinds of products, their most marked effects, and the general ways they are formed.

Smog consists of three basic groups of components — oxidants, aldehydes, and aerosol formers — plus several lesser compounds. Oxidants, the most important group, are defined loosely as anything besides oxygen that is in the air and is an oxidizing agent. Actually, concern focuses on those members of the group that furnish particularly reactive forms of oxygen. The best known of these is ozone, O_3, but other important ones are the organic peroxynitrates — PBzN (peroxybenzoylnitrate) and the PAN's (peroxyacylnitrates). Smog damage to plants and materials, and some of the eye irritation, are attributable directly to these oxidants.

The aldehydes get credit for most of the eye irritation. The most common components are formaldehyde, that foul-smelling stuff that biologists pickle frogs in, and acrolein, which many a chemist recalls as the worst smelling, eye-stingingest stuff he ever worked with.

The aerosol formers cause the typical smog haze. Composed mostly of hydrocarbons with high molecular weights, the aerosols reduce visibility. They may be health hazards, too. Carcinogenic compounds have been found in smog aerosols, but their origin and their effect in the concentrations noted are uncertain. In any case, if the aerosols were eliminated, they wouldn't be missed.

Much of the complex chain of chemical reactions that produces this noxious potpourri called smog begins with a mixture of nitrogen oxides in the air. These oxides form in combustion processes at high temperatures, most notably the combustion of gasoline in motor vehicles and of coal, fuel oil, and natural gas in power plants. Some of this mixture is nitrogen dioxide, NO_2, but most of it is nitric oxide, NO. However, the NO eventually reacts with the oxygen of the air to produce NO_2:

$$2NO + O_2 \longrightarrow 2NO_2.$$

In the dark the reaction would stop right there. But, sunlight causes the reaction:

$$NO_2 \xrightarrow{\text{sunlight}} NO + O,$$

yielding very active oxygen atoms, which, in turn, react quickly with atmospheric oxygen molecules to form ozone:

$$O + O_2 \longrightarrow O_3.$$

If no other reactive species were on hand, the ozone would be destroyed rather quickly by the NO in the air:

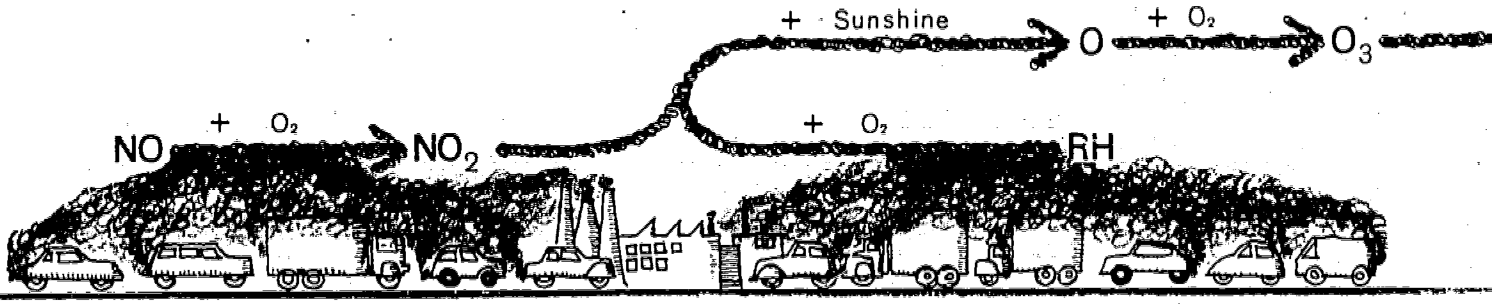
$$O_3 + NO \longrightarrow O_2 + NO_2.$$

However, the hydrocarbons and carbon monoxide that inevitably are present in the atmosphere with nitrogen oxides react either to scavenge NO from the air or to hasten its oxidation to NO_2. This keeps the amount of NO low enough to prevent the last reaction above from eliminating ozone, although this reaction does go on to the extent that it moderates the ozone level somewhat.

The NO_2-NO-O series of reactions doesn't represent the only way that ozone or other oxidants form. With additional ozone produced by hydrocarbon and other organic vapors reacting with oxygen, the concentration of oxidants reaches serious levels in the atmosphere more frequently than otherwise. The highly complex reactions involving the organic oxidant formers are one of the more important, but probably least understood, parts of the reaction chain that culminates in today's smog.

You won't be far wrong if you point to the oxidants, particularly ozone, as *the* bad actors in the smog story. In addition to damaging plant life and materials directly, they play an indirect role in creating eye irritants and other detrimental products. For instance, ozone reacts with hydrocarbon vapors in the air to give aldehydes, according to the general scheme:

$$R{=}CH_2 \text{ or } R{-}CH_3 + O_3 \longrightarrow R{\cdot}CHO + H_2O + O_2.$$



Ozone also produces peroxynitrates, the most significant of the other oxidants, via the general route of:

$$O_3 + NO_2 + R{=}CH_2 \text{ or } R{-}CH_3 \longrightarrow R{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}O{-}O{-}NO_2.$$

In these equations, R stands simply for the rest of any organic molecule; the composition and reactivity of these radicals, and thus of the hydrocarbons, vary considerably. Hydrocarbons with only C—C and C—H bonds (paraffins) are relatively unreactive, and they contribute little to the formation of smog. Hydrocarbons with C=C bonds (olefins) are quite active, and by reacting with oxidants, they produce most of the harmful compounds in photochemical smog other than the oxidants themselves.

Aerosol formation is another poorly understood part of photochemical smog chemistry. Nearly all organic vapors emitted into the atmosphere are too volatile to condense of themselves; but somehow the hydrocarbons react, again under the influence of sunlight and oxidants, to form the higher molecular weight hydrocarbons that do condense, perhaps on airborne particles, to cause smog haze. As with other hydrocarbon reactions, the probability that these reactions will occur varies considerably, depending on the composition and concentration of the individual hydrocarbons involved.

All in all, the chemistry of smog is an exceedingly intricate interplay of competing reactions, some benign and some insidious. Unraveling this tangle is one of the critical challenges facing technologists today.

REGULATING SMOG

When the political, social, and economic complications of abating photochemical smog are added to the technical rigors of dealing with its formation, the difficulties of controlling smog become fully apparent. To achieve such control, we must answer three complex questions: (1) What airborne species of matter count in smog formation and its effects? (2) At what concentrations do the active species begin to make a nuisance of themselves? (3) What regulations or schedule of regulations can be reasonably imposed to bring these active species within tolerable limits?

Obviously, the answer to the third question depends on the responses to the first and second. Yet at the moment the first two are only partially answered. For instance, we know that hydrocarbon vapors are essential to forming smog; however, many of the 150 or more different hydrocarbons identified in auto exhaust have little or nothing to do with smog directly. Methane, for example, is the most common hydrocarbon in the atmosphere, but as related to smog, it's an innocent bystander. On the other hand, a very reactive component like 2-methyl-2-butene can cause trouble even at concentrations of less than a fractional part per million in the atmosphere.

Nevertheless, it makes no sense to sit and wait to learn everything before moving to curtail smog. We know enough about its causes, effects, and control to allow us to make a big dent in the problem, even if ongoing work is needed to control it completely. The attack that can be mustered today is to use what is known to set the most reasonable criteria and standards possible, to continue research aimed at gaining better understanding and improved control methods, and to upgrade the criteria and standards as increased knowledge points the way.

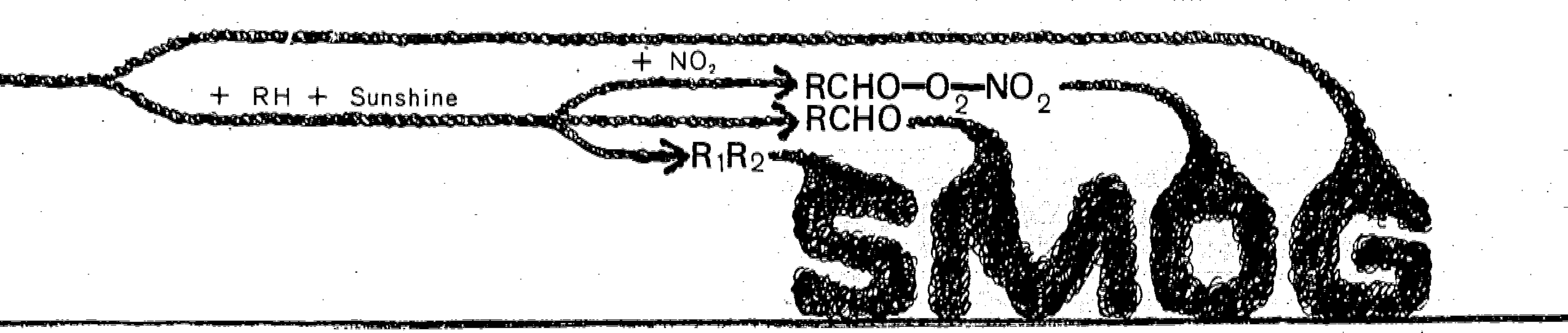
This is generally the approach laid out in the Federal Air Quality Act of 1967 (Public Law 90-148). The Act assigns to the National Air Pollution Control Administration (NAPCA) the job of developing air-quality criteria and control-technique information using the latest, most authoritative data on the causes, effects, and control of air pollution*. The states, then, are to employ these criteria and the control information to establish standards in each of the Air Quality Control Regions designated by NAPCA. Although the criteria are universal, the regional approach to setting standards is realistic since the problems and their potential solutions differ in various locales (as discussed in an earlier article).

In regard to photochemical smog control, NAPCA has issued criteria for oxidant and hydrocarbon levels, and soon will do the same for nitrogen oxides. These criteria will define the clean air goal for all Regions.

The oxidant and hydrocarbon criteria illustrate how smog can be regulated effectively, despite incomplete knowledge. Although the oxidants have different compositions, and although they aren't easy to separate and identify, this much can be said for sure about them: (1) reactive ozone is present in the highest concentration by far; (2) the test for ozone also works for the worst of the other oxidants; and (3) most ill effects of smog are attributable to oxidant concentration either directly or indirectly through the reactions caused by the oxidants. Since a single test (the oxidation of potassium iodide) can measure all of the most harmful oxidants, it is reasonable to set a criterion for oxidants in terms of the data from that test. Moreover, since the nonoxidizing, but irritating, smog products result from the oxidants' action, the oxidant level is a reasonable indicator of smog levels in general. On this basis, NAPCA has set the maximum allowable level of oxidants at 0.1 ppm (part per million) for the average concentration in the atmosphere during a 1-hour period.

Firming up the oxidant criterion made it possible to establish a hydrocarbon criterion as well. Since hydrocarbons are generally harmful in proportion to their ability to produce oxidants, hydrocarbon limits can be fixed at the concentration necessary to give an oxidant level of 0.1 ppm. Smog chamber experiments (see later) have shown that an average 1-hour level of 0.3 ppm of carbon in organic compounds, methane excluded, will lead to the maximum allowable level of oxidants. NAPCA set hydrocarbon limits at that figure, though that criterion does lump unreactive organics in with the active ones.

*The Air Quality Act of 1970, currently in the making, will be even more pointed in its aims to clean the atmosphere.



These limits, however, are not standards; the NAPCA criteria call out the ultimate goal for smog control. Air Quality Control Regions that can satisfy the criteria can say that they have the problem beat. Standards, on the other hand, are set regionally, and specify the limits that are to be achieved by a given date. They depend on local conditions, available technology, and knowledge of what and how particular components of the atmosphere contribute to smog formation.

Establishing criteria is simpler than setting reasonable standards. Most, if not all, Air Quality Control Regions have to go at the problem step by step, gradually tightening the standards. To upgrade the standards as rapidly as practical will take considerable knowledge, especially of the smog making process and its control, and also skill and cooperation. As better understanding of the process evolves, ways of controlling smog will become increasingly clear. With appropriate R & D and intelligent use of the results, control can be achieved.

DRAWING A BEAD ON SMOG MAKERS

Solving the riddle of smog requires a very delicate approach to a mammoth problem. Critical pollutants might be present in minute amounts, say, a few parts per billion. These must be identified, their concentrations measured accurately, and their effects determined clearly. Moreover, the interaction of such contaminants with other components in equally small concentrations must be adequately described in terms of products, reaction rates, and degree of reaction. The problem is like trying to find half a dozen light-gray ping pong balls that are mixed among enough white ones to make a pile the size of Mt. Rainier. Yet this often is just about what smog chemists are called upon to do. The really strange thing is: they do it.

The Smog Chamber Itself

What makes it possible to learn more about smog is a precisely controlled, closely monitored atmosphere-in-miniature called the smog chamber. Although such chambers come in all shapes and sizes, the one at Battelle-Columbus is typical of the larger units operated around the country. It is 8 feet high, 16 feet long, and 5 feet wide, built from functionally inert aluminum and Teflon. One wall holds 7 eye ports for checking eye irritation. The opposite wall is largely a Teflon-film window, outside of which is mounted a bank of fluorescent lamps to provide irradiation — by simulated sunlight, black light (all ultraviolet), or blue light (partly ultraviolet).

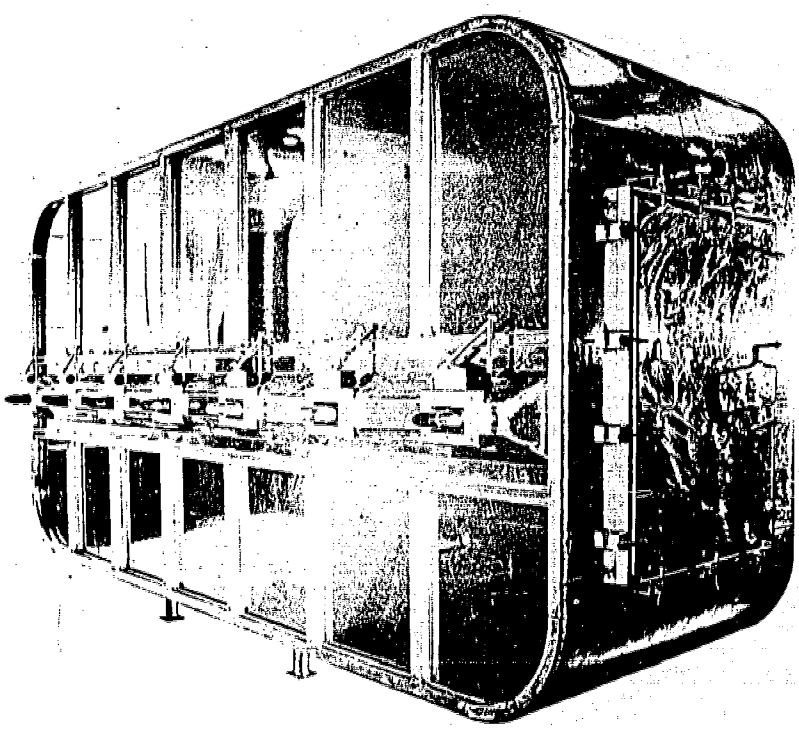
Extremely delicate control of the atmosphere in a smog chamber is essential to obtaining meaningful results. For instance, although fresh air is elaborately purified before injection into Battelle's chamber, it normally is admitted before 4:00 a.m on the day of an experiment, when the Columbus air is [illegible]est.

Moreover, reactions in the chamber must be followed, often continuously, with equipment that is the ultimate in analytical sensitivity. In Battelle's chamber, concentrations of carbon monoxide, hydrocarbons, nitrogen dioxide, nitric oxide, sulfur dioxide, and total oxidant can be continuously monitored down to levels of parts per million or even lower. Intermittent analysis is routine for specific hydrocarbons, aerosols, total aldehyde, formaldehyde, peroxyacylnitrate, peroxybenzoylnitrate, and total sulfur. Other substances can be monitored as required.

The Smog Chamber at Work

Although the smog chamber can be applied to a broad range of air pollution problems, it is used most often today to research the photochemical smog process and to evaluate control schemes. Two case histories of recent Battelle work illustrate how valuable a tool the smog chamber can be.

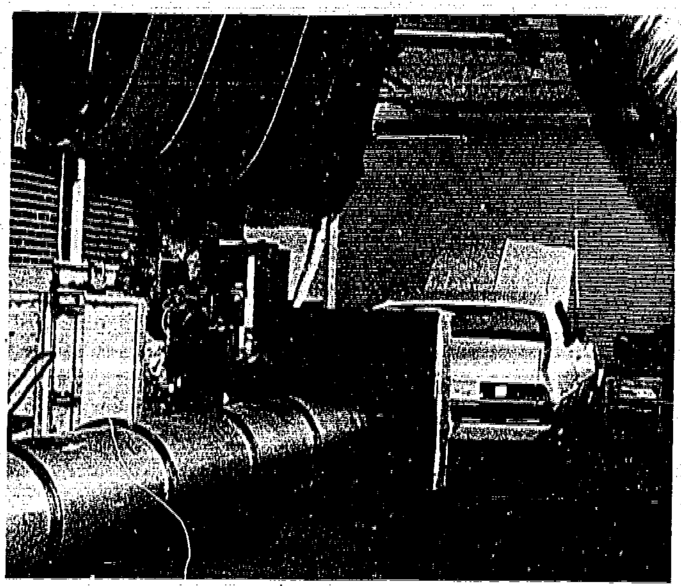
Gasoline and Smog. The way the news media tell it, removing lead could sound like a quick and easy answer to the problem of air pollution from gasoline. Unfortunately, this isn't the case. The oil companies can furnish lead-free gasoline blends that would deliver high performance, but these would not necessarily relieve pollution. The modified blends would contain



Smog Chamber. Chambers like this are the major tool for studying photochemical smog. They allow controlled simulation of smog-forming conditions and precise monitoring of what occurs. The eye ports are used to evaluate potential irritating effects on the eyes of volunteers. Reduced visibility, oxidant formation, and other aspects are checked with instruments. The Battelle-Columbus chamber provides information basic to the development of smog-control devices and facilitates research on the polluting qualities of potential fuels and volatile organic solvents.

higher concentrations of hydrocarbons, especially aromatics, whose smog-forming potential in such blends is still uncertain. As long as this is so, measures like eliminating lead from gasoline may only substitute new troubles for old ones.

Consequently, the American Petroleum Institute initiated a study to obtain information basic to blending gasolines that will perform with reduced air pollution. Part of this effort is to develop an "aerosol reactivity scale" that will rank auto exhaust components according to their tendency to form aerosols, and thus smog haze.



How Much Pollution From Cars? The updated chassis dynamometer allows engineers to evaluate auto emissions realistically while the rear wheels of the car are subjected to resistances that reproduce typical driving conditions. Exhaust gases and particulates are analyzed after they have been thoroughly mixed (in the large duct) with air as in normal car use.

The project team is studying the exhaust from various leaded and unleaded gasolines. The exhaust is generated by running a car on a chassis dynamometer, a machine that puts the vehicle through the Federal Driving Cycle, simulating urban driving conditions. Samples of the exhaust are light-irradiated in the smog chamber while changes in the exhaust composition are monitored by gas chromatography. About 100 different components are followed, some in concentrations as small as 5 parts per billion. The chemical measurements are correlated with the reduction of visibility by the haze that forms.

While still in progress, the study has already shown that some aromatics, despite reports to the contrary, are efficient aerosol formers. This is the type of information that petroleum refiners need to produce low-pollution-potential gasolines.

Organics From Stationary Sources. People generally identify the smog problem with motor vehicle exhaust only. However, a fair share of the active organics in the air comes from what are called stationary sources — paints, lacquers, cleaning fluids, solvents, and organic process chemicals of various sorts. Consequently, two areas, Los Angeles and San Francisco, have found it worthwhile to set up some controls on using these substances.

The development of these controls is a striking example of cooperation between industry and government. The cities agreed not to apply blanket regulations, but rather, to limit those organics that are active in photochemical smog formation. Industry, especially the paint and solvents people, cooperated with the cities in setting up regulations. The National Paint, Varnish, and Lacquer Association helped pave the way by sponsoring research to assess the relative reactivity of 45 useful, but volatile, organic compounds.

The point is that in many uses, several formulations will do the job equally well at about the same cost. If the photochemical smog reactivity of various components is known, an active formulation can be replaced with an inactive one. Justifiably, manufacturers have objected to changing the formulation until the smog reactivity of the components was pinned down.

Smog chamber studies provided this kind of information. The relative reactivity of each of the 45 organics was ranked according to its ability to: (1) produce oxidants, (2) form formaldehyde, (3) irritate eyes, and (4) promote the formation of NO_2. The rankings based on each individual effect were also combined into a relative reactivity ranking that integrated the four effects. As a result, an array of components that may be conducive to smog formation can be examined and, if necessary, eliminated from a formulation on a sound technical basis.

WHAT'S AHEAD

How should smog technologists, with their smog chambers, weather maps, and crystal balls, go about solving today's photochemical smog problem? Initially, they took the obvious way — looking to decrease the amounts of air pollutants across the board. However, as we have pointed out, this is not always practical; it might be unsound economically or it might fail to yield the desired result. For instance, reducing low reactivity hydrocarbons in the atmosphere would have little or no effect on smog formation.

Realizing that there will always be some emissions, industry prefers to tailor them. The concern is focused less on how much hydrocarbons get into the air, and more on how harmful are the emitted hydrocarbons — e.g., does the process release active olefins or neutral paraffins? The goal of controls, then, is to decrease smog by reducing the emission of reactive hydrocarbons.

The above studies for the petroleum and the paint and solvent industries exemplify sound approaches to resolving photochemical smog and controlling it. More industries are likely to follow these examples as emissions are related to levels of compounds in the atmosphere and, in turn, to the products of atmospheric photochemistry. The more we identify reactive-hydrocarbon emissions and the more we learn about their role in the photochemistry of the atmosphere, the nearer we come to licking photochemical smog.

WHAT ABOUT AIR POLLUTION BY POWER PLANTS?

by William T. Reid

GREAT BLACK PLUMES belching from grimy stacks were once a sure sign that electricity was being generated. Power plants were dirty for their neighbors and dirtier yet for their workers. But, not anymore. Today's huge fuel-burning electricity-producing central stations, some costing over a quarter billion dollars, are impressive examples of space-age engineering design and technological advances. Their stacks, as high as 1,250 feet and worth more than a million dollars, discharge barely visible plumes into the air under most conditions. Nevertheless, pollutants are there.

HOW MUCH POLLUTION?

Generating 1 kilowatt-hour of electricity produces a small amount of emissions — typically, 1/6 cubic foot of sulfur dioxide gas (SO_2) when burning coal or fuel oil; 1/20 cubic foot of gaseous nitrogen oxides (NO_x) when burning coal, oil, natural gas; and less than 1 ounce of fly ash when burning ...l. Some 1,000 Btu of sensible heat — nominally 1 percent of the heat required per hour by the average residence in winter — also goes up the stack for each kilowatt-hour generated. The typical household uses 19 kilowatt-hours a day.

These numbers alone aren't particularly disturbing. But when we multiply them by the billions of kilowatt-hours generated today, the true significance of the power-plant polluting problem becomes evident. For example, the electricity used in the U. S. during one peak midsummer week in 1970 came to 33.3 billion kilowatt-hours — 5.5 percent more than in 1969, which, in turn, was 9.3 percent greater than the 1968 peak.

ONE WEEK'S EMISSION OF POLLUTANTS BASED ON 33.3 BILLION KILOWATT-HOURS* OF ELECTRICITY GENERATED

	Pollutant From Total Fuel Burned, tons			*Heat in Stack Gas, million million Btu*
Fuel	*SO_2*	*NO_x*	*Fly Ash*	
Coal	232,000	31,000	415,000	16.4
Oil	48,000	6,000	—	2.9
Gas	—	14,000	—	7.7
Total	280,000	51,000	415,000	27.0

The table here shows the amount of pollutants released during such a peak week. This mass of effluents is a real cause for concern, though on an annual basis, power plants pollute the air at only one-fourth the rate that automobiles and trucks do. A further point is that most of the power plants burning coal and oil are located east of the Mississippi River. Hence, pollutants concentrate in the East at about twice the rate they would if the plants were scattered evenly over the East and West.

If we consider the tremendous air mass into which these emissions discharge, the pollution from power plants appears less formidable. The U.S. east of the Mississippi covers roughly 1.5 million square miles. Since the weight of the air over each square mile is 30 million tons, this area supports some 45 million million tons of air. If the 317,000-ton total output of SO_2 and NO_x from the coal and fuel oil burned during the peak week mentioned here were mixed thoroughly into this air mass, the concentration of pollutants would be only 0.007 part per million parts of air. The wag who said, "Dilution is the solution to pollution," had a point.

At the moment, no one is ready with a way to disperse pollutants uniformly into the atmosphere, and no one knows how fast the atmosphere would cleanse itself of such contaminants. However, stacks taller than 1,000 feet have been built and may become commonplace one day; stacks that go up higher than 2,000 feet seem most unlikely. A more feasible method of raising flue gas to greater altitudes is to use vortex

*Assumes that: sulfur content of coal and fuel oil averages 2.2 percent; heat rate is 9,000 Btu per kilowatt-hour for all fuels; and coal contains 10 percent of ash, with 75 percent of this ash passing to the stack in the absence of any dust-collecting systems.

projectors, i.e., "smoke ring" generators. These possibly could boost the flue gas to 5,000 feet, representing 3 or 4 times the present rise of buoyant plumes. Battelle-Columbus engineers have demonstrated the basic feasibility of the process in the laboratory — using a novel means of harnessing the energy in the moving flue-gas stream to produce the rising gas ring.

Releasing flue gas at heights on the order of 5,000 feet looks safe enough. But in view of the doubts about the wisdom of exhausting water vapor from SST's at 50,000 feet and above. there may be some maximum altitude above which flue gas, with its high water content, should not be vented. Until that is determined, dispersing flue gas at levels above 5,000 feet seems unwise.

LIMITING AIR POLLUTION TODAY

Three pollutants from power plants cause the most concern: sulfur oxides, nitrogen oxides, and particulate matter. Minor pollutants include carbon monoxide, generally in concentrations below 100 parts per million, and some 9 polynuclear aromatic compounds, which usually total less than 1.4 pounds in 100,000 tons of flue gas. For now, at least, these minor ones are being ignored while we learn how to handle the major culprits.

Dealing With Sulfur Oxides

Sulfur oxides (99 percent SO_2 and about 1 percent SO_3) can be controlled through three basic approaches: (1) burning a low-sulfur fuel, (2) desulfurizing existing fuels, or (3) removing sulfur oxides from the flue gas.

Using Low-Sulfur Fuels. These are in limited supply, at least where they are needed. Crude oils from North Africa, Nigeria, and the Far East are naturally low in sulfur, and fuel oil produced from these crudes generally contain less than 1 percent of sulfur. But the bulk of the fuel oil doesn't reach the U. S. market; most of our supply comes from sources with high sulfur content, reaching 5 percent in some cases.

The reserves of coal with less than 1 percent of sulfur are ample — more than 1 trillion tons altogether. However, of this huge energy pool, about 80 percent — subbituminous coal or lignite — is found far from our eastern consuming centers. Much of the remaining low-sulfur bituminous coal is reserved for metal production. About one-fourth of our total known reserves is bituminous coal averaging 2.2 percent of sulfur. These reserves, mostly located in the eastern or midwestern states, are the main source of energy for conversion to electricity. All but a small fraction of this sulfur appears as SO_2 in the flue gas.

Natural gas contains no sulfur, and power plants fired with gas contribute no SO_2 to the atmosphere. However, the supply of natural gas is limited, and with proven resources shrinking rapidly, the use of this premium fuel by public utilities is being restricted. Although about 20 percent of the electricity generated in 1970 comes from natural gas, that figure is expected to drop to 15 percent by 1975, and to 13 percent by 1980.

Desulfurizing Fuels. On the average, half of the sulfur in coal is present as pyrites (iron sulfides) and half is combined chemically with the complex coal structure. Depending on the size of the pyrites particles, they can be removed, at least in part, by stage grinding or by float-and-sink coal washing. Battelle-Columbus has demonstrated that electrostatic forces can be used to separate pyrites from crushed coal, but the process hasn't yet been adopted commercially. None of the organic sulfur can be removed without destroying the coal's molecular structure, e.g., by converting it into a fuel gas. Hence, sulfur can be taken from coal only to a limited extent, and at costs, for froth flotation for example, ranging upward to $1 per ton, adding some 15 to 30 percent to the fuel cost.

Fuel oil is more amenable to desulfurizing; generally, the oil is treated with hydrogen to form hydrogen sulfide gas, which then can be separated from the liquid. This hydrodesulfurizing has come on strongly over the past few years, but the cost is still high. Desulfurizing fuel oil to acceptable levels costs from 50 cents to $1 per barrel, adding a fourth to a half to the original price of the oil.

Removing SO_2 From Flue Gas. Over the past 3 years, great interest has developed in treating flue gas to eliminate SO_2. More than 20 processes are on the books. Some of these are obviously unsuited to a power plant, but several are attractive. However, problems abound. The materials-handling problem alone is of a size seldom faced by engineers. A typical, large boiler furnace can send more than 50,000 tons of gas up the stack a day; even with SO_2 making up only about 0.25 percent of it, this means that 125 tons of SO_2 must be removed daily.

Six major schemes are getting most attention. Historically, the first is simple water scrubbing of the flue gas to carry off SO_2 in solution. Its use began in 1932 in 2 large power plants in London on the Thames. Costs of the process have discouraged more installations.

One appealing scheme is based on injecting pulverized limestone into hot flue gas; the gaseous SO_2 is converted into solid $CaSO_4$ and carted away with the fly ash. The only additional costs are for limestone handling equipment, pulverizers, injection systems, and facilities for removing the spent solids. Full-scale tests are now under way by TVA and the National Air Pollution Control Administration (NAPCA) to determine costs and effectiveness, and to identify operating difficulties. Battelle-Columbus has been studying basic problems in this field since 1966, beginning with calculations of the ability of limestone and dolomite to react with SO_2 in the flue gas. For the past 3 years, research for NAPCA has focused on measuring the rates of the chemical reactions under conditions closely simulating those in full-scale boiler furnaces, and this work is continuing.

In a related method, limestone is injected into the boiler furnace where some of it reacts with SO_2. The remaining unreacted lime is caught by a water scrubber just ahead of the stack to form an alkaline solution that picks up more SO_2. Two full-size boiler furnaces are using this process and a third is being built. In addition to capturing more than 80 percent of the

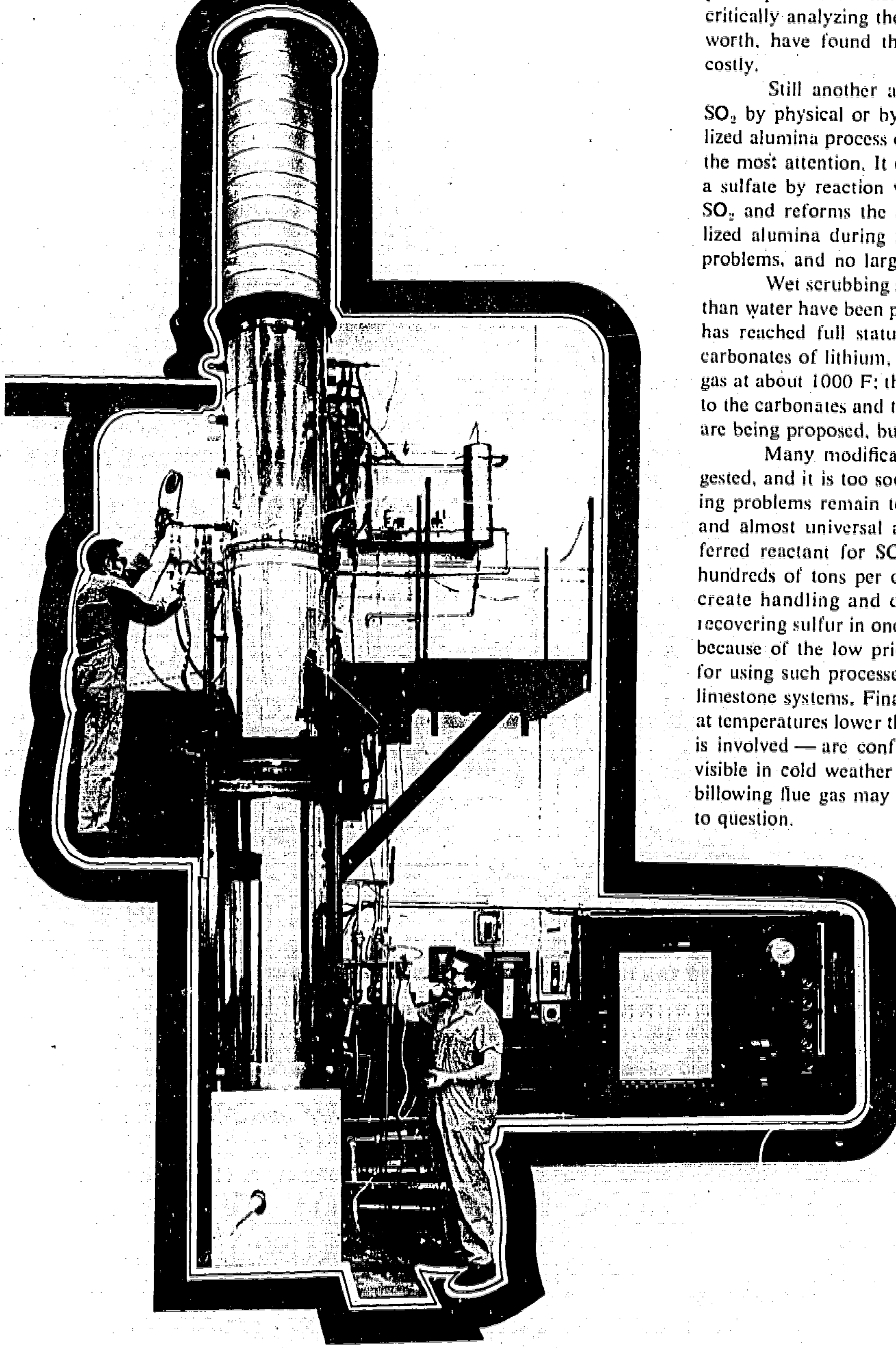
SO_2 from the flue gas, this system also removes essentially all the particulates so that an electrostatic precipitator isn't needed. However, some operational troubles have arisen.

A basically different process converts the SO_2 into SO_3 when flue gas, cleaned by taking out the particulates, is passed through a fixed catalyst bed. The sulfuric acid that eventually results is collected in a condenser ahead of the stack. The process will be installed in a full-scale unit at a new midwestern power plant in the near future. Battelle-Columbus engineers, in critically analyzing the process to aid the utility in assessing its worth, have found that converting an existing plant may be costly.

Still another approach is based on sorbents capturing SO_2 by physical or by chemical means. In this area, the alkalized alumina process of the U.S. Bureau of Mines has received the most attention. It changes particles of alkalized alumina to a sulfate by reaction with SO_2; later regeneration releases the SO_2 and reforms the absorbent. Size degradation of the alkalized alumina during repeated handling has presented serious problems, and no large installations have been built.

Wet scrubbing systems that use chemical reagents rather than water have been proposed by many investigators, but none has reached full status. One attention-getter employs molten carbonates of lithium, sodium, and potassium to scrub the flue gas at about 1000 F; the resulting sulfates are reconverted later to the carbonates and the sulfur is recovered. Pilot plant studies are being proposed, but no full-size installations are in sight.

Many modifications of these schemes have been suggested, and it is too soon to rate them competitively. Engineering problems remain to be solved in every case. The low cost and almost universal availability of limestone make it a preferred reactant for SO_2; but the quantities required — many hundreds of tons per day for a single, large boiler furnace — create handling and disposal difficulties. Systems based on recovering sulfur in one form or another are not appealing now because of the low price of sulfur. This reduces the incentive for using such processes since they usually cost more than the limestone systems. Finally, the methods that discharge flue gas at temperatures lower than 200 F — especially if water washing is involved — are confronted by stack plumes that are highly visible in cold weather owing to condensing water vapor. The billowing flue gas may be clean, but public acceptance is open to question.



Good Riddance. Limestone's affinity for sulfur dioxide is well known. Exploiting this characteristic in boiler furnaces can keep SO_2 from getting out the power plant stack. Battelle-Columbus engineers have experimented in the rig shown here to learn how to use limestone effectively and economically in removing SO_2 from hot flue gas.

In short, pollution by SO_2 is being studied extensively. Control is assured, but the costs of cleaner flue gas from power plants still hurt.

Treating Nitrogen Oxides

Although the major focus is on SO_2, nitrogen oxides (NO and NO_2, collectively called NO_x) in flue gas are not being ignored. Some NO_x forms in all high temperature flames when nitrogen in the air reacts with active oxygen species in the flame. Generally, the higher the temperature, the more NO_x is produced. Also, both coal and fuel oil contain nitrogen compounds that are suspected of causing additional NO_x during combustion, though very little is known about them. Natural gas is free from such substances, but NO_x still forms by flame reactions. Thus, all fossil fuels contribute in this way to air pollution.

Two basic procedures reduce NO_x emissions: burning at a maximum temperature that is as low as possible, or operating the boiler furnaces fuel-rich to eliminate highly active forms of oxygen from the flame.

Only the first of these methods is workable in large boiler furnaces. Flame temperature can be held down in two practical ways without cutting back on total heat output: (1) by first admitting only part of the air into the burner region and then, after combustion is partially completed, supplying the rest of the air needed, thus controlling the rate of combustion, or (2) by recirculating appreciable amounts of flue gas into the flame region, thus limiting the maximum temperature both chemically and physically. Both schemes are most adaptable to gas-fired and oil-fired boiler furnaces, but both pose serious engineering problems when pulverized coal is burned.

Physical chemists have studied NO_x in depth. They have given us a good deal of information on how it forms from, and reverts back to, nitrogen and oxygen. The basic chemistry is well understood. But when we deal with carbon/hydrogen complexes in fuels, the reactions become much more involved and we can't yet predict equilibrium concentrations and reaction rates. Such basic information will be developed in the laboratory eventually, though it appears that research in large boiler furnaces will be necessary to provide workable design information.

Handling Particulate Matter

Of the three fossil fuels, only natural gas creates no polluting inorganic particles (fly ash). Coal, with an ash content usually around 10 percent, is the worst offender, but fuel oil's 0.1 percent ash also can be troublesome.

The quantity of fly ash emitted by a boiler furnace that burns pulverized coal depends mostly on how the coal is fired. In cyclone furnaces, where heat releases at a high rate, a molten layer of coal/ash slag inside the horizontal cylindrical combustor captures all but 10 percent of the ash, thus keeping the amount of dust in the flue gas low. Conventional slag-tap furnaces, with a pool of molten slag on the hearth, let about 50 percent of the ash leave the furnace. In dry-bottom furnaces, where the ash is only partly sintered, as much as 80 percent of the ash might go up the stack.

The heavier bits of this fly ash are captured by mechanical collectors using inertial forces and are retained in hoppers. Particles smaller than about 10 microns escape such collectors; they can be caught only by electrostatic precipitators or, in rare instances, by bag filters. Precipitators do yeoman service in removing particles when the units are large enough to keep the flue gas moving through them slowly. The collection efficiency of generously designed and well maintained precipitators can be better than 99 percent.

High electrical resistivity of the fly ash degrades precipitator performance. For low-sulfur coal, the fly ash resistivity may be up because the flue gas doesn't contain the little SO_3 needed to put an electrically conducting film on the particles' surfaces. A decade ago this condition would have been rectified by switching to a higher sulfur coal, or even by bleeding some sulfuric acid or dumping some sulfur into the flue gas stream. Today such expedients are unthinkable. The resistivity problem disappears at flue gas temperatures well above 350 F, but the precipitators then become more expensive because they must be larger to handle the expanded volume of the gas.

The troubles aren't so bad with oil, since only about one hundredth as much ash is involved. Though most oil-fired boiler furnaces are not set up to clean the flue gas, they can be equipped with precipitators or with bag filters when cleaner air is demanded.

Fly ash can be removed satisfactorily from flue gas with present technology. The major aim now is to do it more completely at an acceptable cost.

PROSPECTS

Public utilities are in business to generate electricity, not to process chemicals. Nothing could be wanted less around a power plant than a complicated chemical process for cleaning flue gas that might go awry and force an outage. The utilities would much rather burn low-sulfur fuel to eliminate SO_2 and modify the burners to keep from forming NO_x. This dilemma of the utilities may be resolved eventually by developing combustion systems that are quite different from today's.

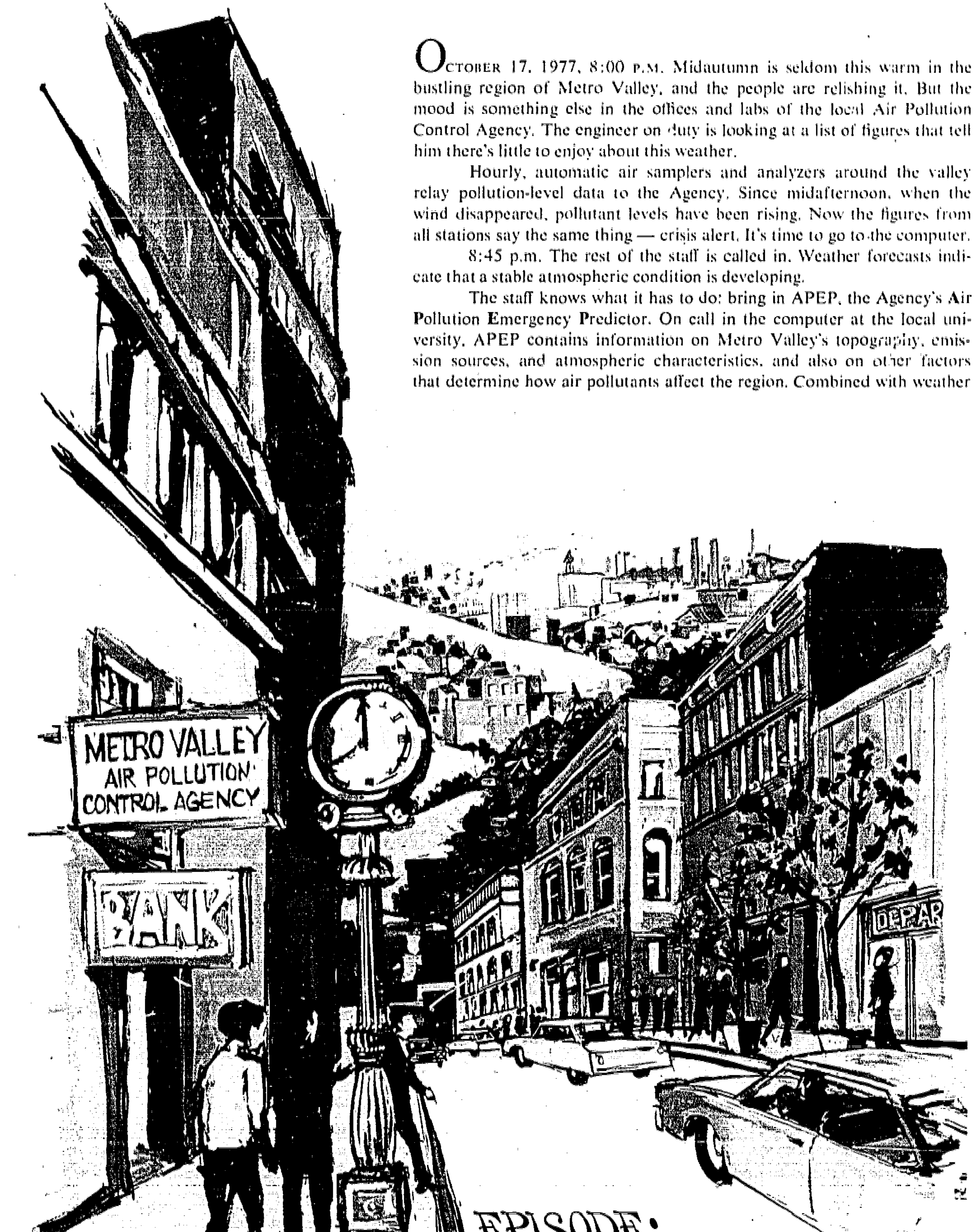
Faintly visible on the horizon is a new method of burning fuels that could lead to cleaner air. The fluidized bed is the key. It involves a stream of air moving slowly through a bed of inert material and causing a "boiling" action. Such a system can become a combustor if the bed material is heated to about 1500 F and a fuel, either oil or crushed coal, is admitted. If the bed material is limestone, the resulting lime will react with SO_2 as it evolves during combustion. Further, because the temperatures in fluidized systems are remarkably uniform and can be held as low as 1500 F, little NO_x forms. Much R & D effort is being devoted to learning whether such combustors can be used in large central-station power plants. The concept is not new, but the application is.

Another possibility is an advanced power cycle based on gasified coal. After gasifying under, say, 100 psi pressure, the hot fuel gas would be stripped of sulfur, the clean gas would be burned in a pressurized boiler, and the hot products of combustion would be expanded through a gas turbine. The thermal efficiency of the cycle should be favorably high; the combustion products would be clean. This cycle might look expensive, but compared to the cost of the flue-gas cleaning schemes, it might be economically attractive indeed. Projections remain uncertain while less novel schemes are being evaluated.

Clean air will not come easily or cheaply. But the problems involving large-scale generation of electricity are just the sort that spur on any research man worthy of the name. It will be interesting a decade hence to see how it all comes out.

EPISODE: A Case of Applied Atmospheric Dynamics

by Philip R. Sticksel and Stephen D. Ban



OCTOBER 17, 1977, 8:00 P.M. Midautumn is seldom this warm in the bustling region of Metro Valley, and the people are relishing it. But the mood is something else in the offices and labs of the local Air Pollution Control Agency. The engineer on duty is looking at a list of figures that tell him there's little to enjoy about this weather.

Hourly, automatic air samplers and analyzers around the valley relay pollution-level data to the Agency. Since midafternoon, when the wind disappeared, pollutant levels have been rising. Now the figures from all stations say the same thing — crisis alert. It's time to go to the computer.

8:45 p.m. The rest of the staff is called in. Weather forecasts indicate that a stable atmospheric condition is developing.

The staff knows what it has to do: bring in APEP, the Agency's Air Pollution Emergency Predictor. On call in the computer at the local university, APEP contains information on Metro Valley's topography, emission sources, and atmospheric characteristics, and also on other factors that determine how air pollutants affect the region. Combined with weather

forecasts, air analyses, and present and projected emission levels, the program can predict pollution levels anywhere in the valley for up to 48 hours with a minimum accuracy of 75 percent.

9:35 p.m. APEP confirms the worst. Metro Valley's warm, still air is about to become a stagnant pool of slow poison. Unless action is taken, pollution will reach toxic levels in about 12 hours. The first deaths stemming from pollution can be expected in 24 hours. No relief is anticipated within 48 hours, the time span of APEP's prediction capability.

The community's authorities are called in. To prepare for their arrival, the staff asks APEP more questions: How much must emissions be reduced to keep pollution at safe levels? What sources are likely to do the most harm? What controls will bring emissions in line — with the least disruption to the community? By the time the town fathers arrive, APEP has transmitted answers and the Agency is ready to present a plan.

Fortunately, the authorities are easy to convince. They recall the week 20 years before when such an episode went unchecked. That week the air killed dozens and sickened hundreds. Many suffered aftereffects for years.

11:45 p.m. to October 18, 9:00 a.m. Controls are activated. Several industrial plants are shut down. The electric company cuts its output 50 percent; power rationing is introduced. Auto travel is curtailed sharply.

October 18 to October 20. The staff is collecting information and feeding it into the computer around the clock. Each new set of air sample analyses, all new weather data, and all source-emission data are put through the computer. New data-collection stations are opened and the information from them is fed into APEP.

Some results are encouraging. By and large the controls do the job; high contaminant levels in scattered areas necessitate some changes, but the original plan is working pretty well. Other results are discouraging. Two days pass without any firm prediction of relief.

October 21. Controls continue to maintain pollution below danger levels. APEP predicts relief early the following afternoon. Some restrictions are eased.

October 22, 2:28 p.m. A good, stiff breeze blows. End of episode — 114 hours and 28 minutes after the crisis alert.

1957 TO 1971: METRO VALLEY'S DILEMMA

Before 1957 Metro Valley was smugly content. Smarting eyes and smoggy skies were just the price you paid for ample profits and full employment at high wages. Controls were sporadic, minimal, and unplanned. Warning cries drowned in the steady hum of prosperity.

The 1957 disaster changed that in a hurry. An awakened Metro Valley made up for lost time. By 1960, controls had reduced air pollution to half the average 1957 level. The community thought it had the problem licked.

But then the good dog, progress, started wagging its dirty tail again. The industries in the valley continued to grow; they enlarged existing plants and built new ones. Additional industry came into the area. This meant more people, more electric power needed, and more cars. After 1960, the new controls were no longer adequate for abating pollution emissions, and the levels started rising again. By 1970, compared to 1960, the community had 25 percent more people driving 67 percent more cars over twice as many passenger miles. Industrial production had increased over half. Power consumption had almost tripled. The result: 13 years after the 1957 disaster, Metro Valley could expect a recurrence at any time. There was only one significant difference; because 25 percent more people lived in the area, the next episode might easily be 25 percent more tragic.

1970 found Metro Valley on the horns of a dilemma. Stricter controls would mean higher costs, and existing measures already cost as much as the traffic thought it could bear. Besides, the problems of solid and liquid wastes were growing apace, putting more pressure on the dollars available for protecting environmental quality.

Moreover, the decade ahead looked like one of continued growth and economic expansion — just what the community wanted. Prosperity is a hard habit to break. The cost of pollution abatement would have to be met without limiting Metro Valley's further economic growth.

Considerable improvement in the technology of emission source control could be expected, certainly; but at best, it looked like Metro Valley would need to be lucky just to keep emission levels unchanged for the next couple decades. Growth in emitting sources was sure to keep up with any reduction in emission rates, at least for the time being. Surely, noxious emissions could eventually be eliminated at reasonable cost, but Metro Valley couldn't afford to choke to death while waiting.

A change in policy was required. In the 1960's, Metro Valley had put almost all its efforts into cleaning up emissions at the source. This policy was inadequate. Everything that could be done had been done, but the problem was still there. Consequently, in 1970, Metro Valley made a big decision: to resort to atmospheric dispersion — ways would have to be found to use the great volume of atmosphere to dilute emissions to tolerable concentrations.

The decision wasn't arrived at lightly. Dispersion is a second best method, but Metro Valley had no choice. It was sitting on a time bomb and couldn't wait for the ultimate solution. The city fathers proceeded to allocate funds for an atmospheric dispersion program to supplement its source control program, and went looking for help.

Metro Valley authorities turned to a large research organization, and spelled out the situation to that institute's personnel who were experienced in atmospheric dynamics and air pollution transfer. These specialists formulated a plan of attack, which the community agreed to. Early in 1971, the research team was set to work on helping Metro Valley get along with its atmosphere.

METRO VALLEY'S ATMOSPHERE

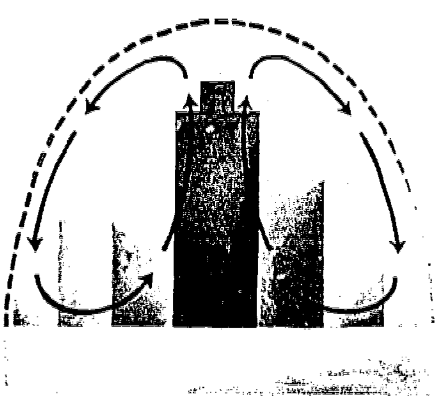
In a sense, it's strange that air pollution is a problem. With the whole sky available to disperse emissions, it would seem that air pollutants would never reach noxious or toxic concentrations. As a matter of fact, more particulate material discharges into the atmosphere from the burning of vegetation (e.g., from the premeditated burning of agricultural refuse and from inadvertent forest fires) than from any other single type of source. However, this burning usually takes place in open areas away from any large population mass, and the smoke is well scattered before it has a chance to affect any great number of people. Consequently, agricultural refuse fires or forest fires aren't often mentioned as an important gen-

erator of air pollution. If industry, power plants, autos, and people were distributed as widely as these fires, then the concern about air pollution could be reduced to a small fraction of what it is now.

But, people generally cluster their homes and their industries in the largest groups they can manage (or larger). So the atmospheric pollution plague is with us.

The Urban Envelope

Part of Metro Valley's trouble arose from the simple fact that it existed. When cities form, they tend to create an atmosphere all their own, called the urban envelope, with climate and characteristics different from those of the open country around them.



THE URBAN ENVELOPE

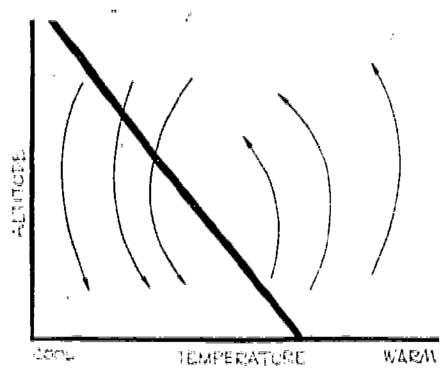
The air is warmer inside the urban envelope than it is outside. Urban buildings and streets absorb a lot of the sun's visible and ultraviolet light and reradiate it as heat. Moreover, much of this radiation bounces back and forth between the walls of the buildings, rather than into the open air. In the winter, the heat generated inside buildings warms the whole area.

This excess heat is the main cause of the envelope effect. Warm air in the central core of a city rises, cools when it lifts above the taller buildings, and then spills out into the suburban areas, where it tends to circulate back along the ground into the central core. There it is warmed again and the cycle repeats itself. Although the center of the envelope may shift slightly downwind from the urban center, buildings serve to hold the envelope in place and to abate the winds blowing through the area. The total effect is something like a great atmospheric dome.

The worst aspect of the urban envelope is that, on a still day, all emissions discharged within it generally remain there. A brisk breeze will break up the envelope, but without that breeze, the result can be nasty indeed. The nub of the problem is the frequency of temperature inversions that clamp the lid on the urban envelope and defeat the forces acting to break it up.

Temperature Inversions

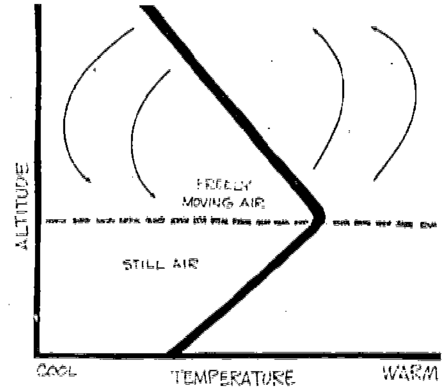
Usually, air next to the ground is warm, and air temperature drops as the altitude increases. Since air tends to



NORMAL TEMPERATURE GRADIENT

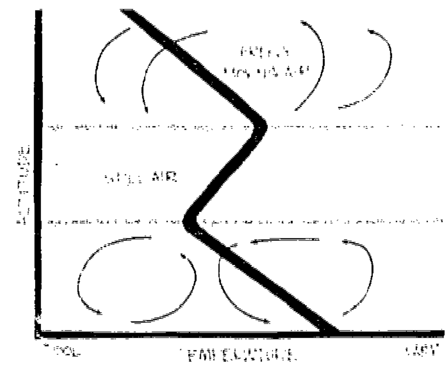
rise when warm and to sink when cool, vertical mixing churns the air and scatters contaminants. However, if the opposite happens, that is, if cool air lies under a blanket of warm air, the layers generally remain stable and little mixing occurs; thus, the contaminants don't disperse readily. This condition, called temperature inversion, is of critical interest to air pollution controllers.

The most common type of inversion — nocturnal inversion — takes place in the wee hours of the morning,



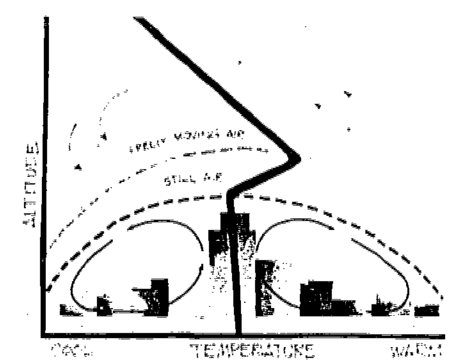
GROUND LEVEL (NOCTURNAL) INVERSION

when the ground has lost the excess heat absorbed during the previous day and cools the immediate air cover. Ground mists, dews, and the typical stillness of the dawn result from such inversions. However, they burn off in the warmth of the day and seldom are troublesome.



ELEVATED (URBAN ENVELOPE) INVERSION

A second, less frequent but potentially more serious, kind of temperature inversion is the subsidence inversion. This forms when warm air in a high-pressure area tends to sink, compressing and warming as it goes. The subsiding warm air, if it descends upon a layer of cooler air, creates a stable condition with little vertical mixing. A subsidence inversion that takes place near the center of a slow-moving high-pressure area, where winds are nil, can persist for days and can cause major troubles. This is what happened in Metro Valley.



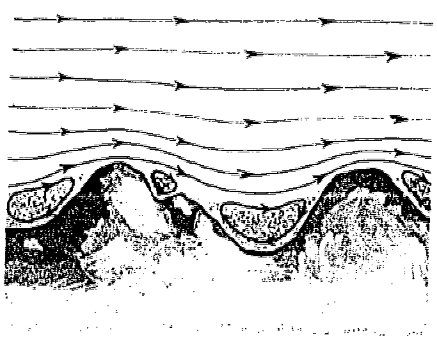
URBAN ELEVATED INVERSION

A third type, known as the urban elevated inversion, tends to seal the flap on the urban envelope. Just how and why it occurs are uncertain, but it's a cousin of the common nocturnal inversion. Like the latter, the elevated inversion forms in the early morning hours, but at altitudes of a few hundred feet

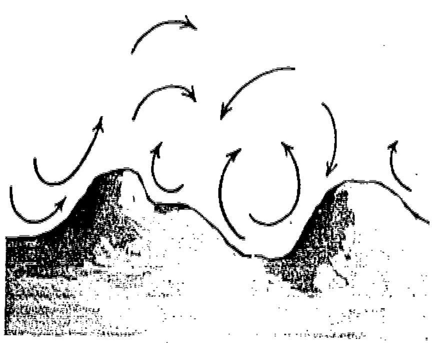
over the city instead of at ground level. Moreover, it can stay on for days. Such inversions, reinforced each night, can hang over cities indefinitely in the absence of wind — particularly if accompanied by a subsidence inversion: and they cause the recirculation patterns that trap air pollutants inside the urban envelope.

Other Features

Another part of Metro Valley's problem is topography. It's enclosed on three sides by hills rising from 500 to



1,500 feet from the valley floor. This limits air circulation further, produces localized pockets of pollution at the bases of the hills, and generally stabilizes and extends the urban envelope.



Metro Valley is luckier in other ways. Its shifting and capricious weather, which means relatively turbulent air, leads to atmospheric mixing that can usually be counted on to flush out the valley and disperse emissions quickly.

However, such turbulence can't always be depended upon. The 1957 disaster in Metro Valley was caused in large part by a subsidence inversion. This inversion, plus the topography, the urban envelope, the concentration of heavy industry and fossil-fuel-burning power plants, and the lack of controls, provided all the essential ingredients for catastrophe. Rarely do all of these come together to cook up such a witch's brew.

1971 TO 1977: METRO VALLEY ADAPTS

The research institute's team of specialists in air pollution transfer and atmospheric dynamics (the AD team) — chartered to investigate Metro Valley's problem — began the program in Spring, 1971. The first step involved gathering data related to the valley and defining what more was needed.

In some categories, Metro Valley was able to supply a lot of accurate data. Topography and large-scale meteorological patterns were well defined. Good information was in hand on sources of emission and their emitting rates. However, little was available on how air circulated from one side of the area to another, and even less on the mixing characteristics of the air immediately overhead. As a result, the data from the city's air sampling program were only of general value; there was no way to tell how representative they were.

The AD team decided on a two-pronged attack. It would try to simulate Metro Valley's atmospheric conditions with a computer model using topographical and large-scale meteorological data, and at the same time, it would run an experimental program to define the small-scale air-circulation patterns. Combining its experimental results, the team generated a well defined model of what the air does in, over, and around Metro Valley. This model, christened ADAPTS (Atmospheric Dynamics and Air Pollution Transfer Simulator), was a tool that the AD team needed to serve Metro Valley. The team could plug data on existing or potential air-pollution sources and their emission rates into ADAPTS, which would then calculate the long-range effects of emission under any given steady-state conditions of the atmosphere.

Air Sampling

One of the first practical results of using ADAPTS was the discovery that Metro Valley's air sampling program needed reorganizing. The data from that program were not representative and several areas where emissions tended to concentrate were not covered. With ADAPTS, the team evolved a program of sampling frequency and location that led to better deployment of sampling stations and to improved input to ADAPTS. Moreover, fewer stations were necessary in view of ADAPTS' ability to analyze data statistically. With fewer stations employed, Metro Valley was able to afford new facilities that would sample and analyze air automatically and with greater accuracy and speed than could the old stations.

Land-Use Planning

ADAPTS quickly proved useful to land-use planners. Thus, it was discovered that an industrial park was to be built just inside the perimeter of the urban envelope, and that emissions from the park would tend to flow along the ground into the downtown area. The park was subsequently relocated where emissions would generally rise and be carried away from crowded areas.

ADAPTS served in other ways, too. In general, land-use planners were able to move land development in directions that took it away from pockets of pollution. They could locate recreational parks and open areas so as to break up the urban envelope's effects, and lay out highways and plant sites along lines where emissions would do minimal damage at ground level. Further, shortly after ADAPTS went on line, new Metro Valley housing was built in places that smelled a lot better.

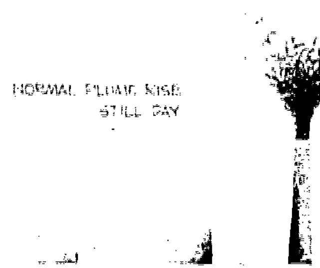
Emission Sources

The problem of emission sources also was attacked with ADAPTS. One of the oldest, most common, and most useful devices for abating air pollution is the tall stack. Unfortunately, when the AD team started work in Metro Valley, the tall stack concept was in disfavor. The argument was that tall stacks didn't eliminate pollution; they only redistributed it. The air might stay clean at ground level close to the source, but the pollutants would merely come to ground a little farther away.

In some ways this was true. One

of the power plants in Metro Valley, for instance, had a stack 1,000 feet high, which was near the practical upper limit of height. This allowed emissions to be carried away from the central city. But ADAPTS was able to show that emissions from this stack frequently grounded on hillsides surrounding the valley — and this was the tallest stack in the valley. The many tall stacks in the area did prevent high ground-level concentrations close to the sources, but the net effect, because of the hills, was often simply to distribute pollutants evenly throughout the valley. The problem was to get the emissions up high enough to escape beyond the hills.

Convincing people that tall stacks could be a way out of Metro Valley's situation was a struggle for the AD team. However, besides ADAPTS data, the investigators had two things going for them — the phenomenon of plume rise, and the technique of generating vortex rings.



Because a plume of smoke is usually much warmer than the surrounding air and leaves the stack with some momentum, it is likely to rise well above the top of the stack before losing its excess heat and its momentum. Then the plume fans out widely and gets on with pollutant dispersal. This plume rise can significantly increase the effective height of a stack on a calm day, when natural scattering tendencies are at a minimum. In many areas, this rise insures that emissions will be well distributed in the atmosphere, even under highly stable (poor mixing) conditions. However, because of the hills, if plume rise were to work for Metro Valley, its height would have had to be doubled or tripled.

At this point, the AD team brought out the vortex ring generator it had been developing in its laboratories. This is a device that gets tall stacks to blow smoke rings. The smoke or vortex ring is a stable form of circulating air that is like a whirlpool turned back upon itself to form a doughnut. For air pollution controllers, this configuration has two important qualities: the ring tends to hold its shape and to retain its momentum. Blown out of a smoke stack, the vortex ring can propel itself upward two or three times the height of normal plume rise before dispersing, and can even pierce temperature inversions.

As ADAPTS figured it, vortex rings from tall stacks would get to an altitude of 3,000 to 4,000 feet over Metro Valley on a calm day — enough to clear the hills on dispersal, and even enough to make little difference to communities beyond the valley. Metro Valley set up several vortex-ring generators in the mid-70's. It was a relatively cheap way to control air pollution.

ADAPTS Begets APEP

With the help of ADAPTS, Metro Valley was getting the jump on its problem. In 1976, although total emissions were almost the same as in 1970, average ground-level concentrations of air pollutants had decreased 45 percent.

However, throughout these advances, the big question remained: Could Metro Valley expect a repetition of its 1957 disaster? ADAPTS said yes. It wasn't likely, but it could happen, and the program spelled out the necessary conditions. A delicate maneuver would have to take place; but if Nature went about things just right, she could stack temperature inversions thousands of feet high over Metro Valley and hold them there for a week or more. ADAPTS said there was about a 3.3 percent annual probability that such conditions could occur.

Beyond this, ADAPTS couldn't say. It was a simulator, not a predictor. It could say *what* might happen, but never *when*. Consequently, Metro Valley added APEP to its arsenal — a very wise move as it turned out. APEP used the same basic information as ADAPTS, but the calculation base was different. ADAPTS was good on steady-state conditions, but poor on variations. APEP could handle hour-by-hour variations for up to 48 hours. Given timely emission and meteorological input, it proved to be a most effective predictor when needed. Moreover, once ADAPTS had been established, APEP was cheap. ADAPTS furnished 90 percent of APEP's input needs.

EPILOGUE

ADAPTS and APEP retired together in 1992. Metro Valley had no further need for atmospheric dispersion control. All industry had installed effective source-control devices or switched to nonpolluting processes. Auto exhausts were under complete control. Electric power was supplied by nuclear utilities located outside the valley. Metro Valley enjoyed the bluest skies, greenest grass, and cleanest clothes it had known since the first factory moved into the valley.

End of story. So — what is fact and what is fiction? In some ways it's almost all fiction; there is no Metro Valley, and no episode. But from another point of view, it's nearly all fact. Today, dozens of metropolitan areas have the kinds of troubles that bedeviled Metro Valley (in the story), and a number of these locales can bank on serious episodes in the foreseeable future.

Moreover, the major points of this story are definitely fact. Source control measures still fall short of eliminating air pollutants, and at least some of this pollution will have to be relieved through realistic atmospheric dispersion. Further, for such approaches to work, urban areas will need specialized technical assistance.

Steady-state simulator programs like ADAPTS are already helping many regions. The know-how for predictor programs like APEP is growing rapidly. Devices such as the vortex ring generator are being developed now. Can they work for your area? You decide — but first, take a deep breath.

FOR FURTHER READING

Where can you look and not find literature on air pollution? Much of this deluge is good, but some of it is extreme, and caution is recommended in assessing various published outlooks. A fine general view of the problem is given in an extensive article entitled "We Can Afford Cleaner Air," in **Fortune**, November, 1965. This outlines the magnitude of the problem and provides rough estimates of the investment cost ($3 billion a year for 10 years) for an 85 percent cleanup of the U.S. atmosphere.

More recent articles from **Fortune** have been collected into a paperback entitled **The Environment** (Perennial Library, 1970)—a topnotch review of the broad aspects of environmental quality. Richard Scorer's **Air Pollution** (Pergamon, 1968) interestingly describes atmospheric problems.

Anyone who is serious about the scientific and technical aspects of the subject should become familiar with the 3-volume work **Air Pollution**, A. C. Stern, editor (Academic Press, 1968). It covers the field both broadly and deeply.

On the sociopolitical side, the **Report of the Environmental Pollution Panel of the President's Science Advisory Committee** (The White House, 1965) is a must, as is **Guidelines for the Development of Air Quality Standards and Implementation Plans** (HEW, Public Health Service, NAPCA, 1969). The first discusses policy approaches to the solution of environmental problems. The second is the handbook for implementing the Air Quality Act of 1967. The Spring, 1968 issue of Duke University's **Law and Contemporary Problems** (v. 33, no. 2) deals with legal aspects of air quality control.

For the economics of air pollution control, a good overview is given in Ronald G. Ridker's **Economic Costs of Air Pollution—Studies in Measurement** (Praeger, 1967). "Air Pollution and Human Health" by Lester B. Lave and Eugene P. Siskin, **Science**, August 21, 1970, presents the economic view in terms of human health.

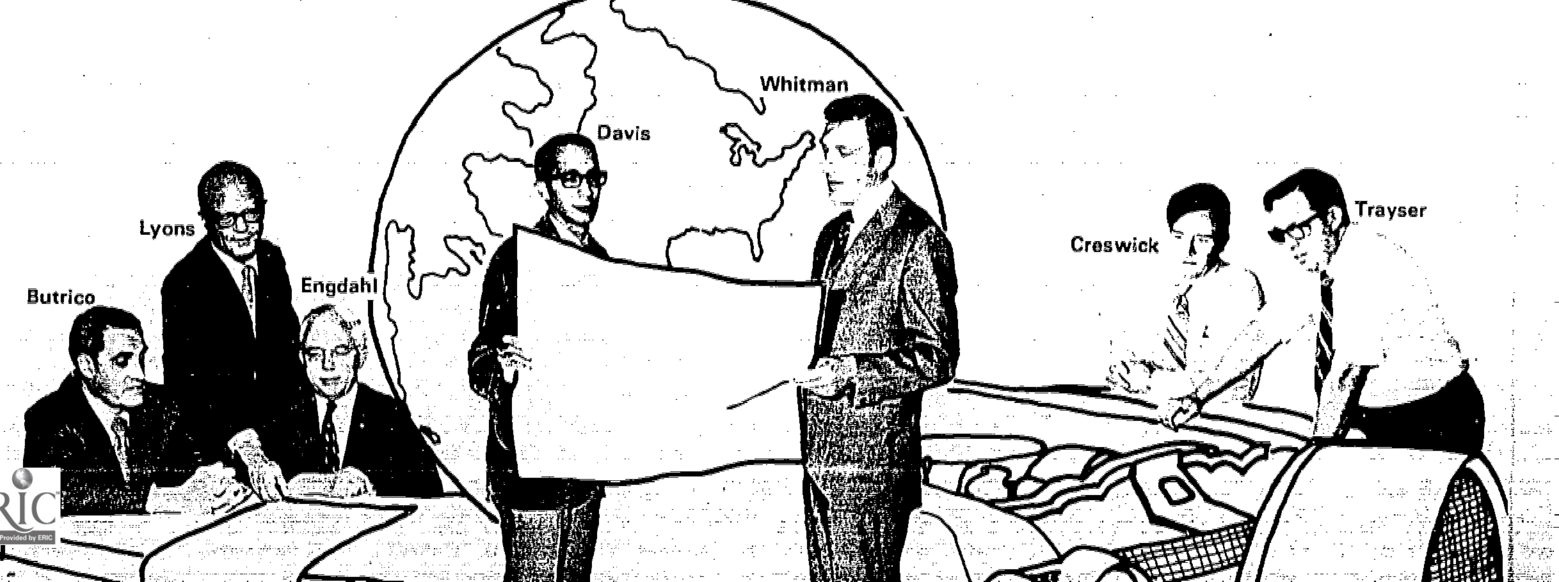
P. S. Myers describes the general state of affairs regarding motor vehicles and their emissions in his paper "Automobile Emissions—A

The Authors

The authors of this issue's keynote paper, **Frank A. Butrico, Richard B. Engdahl,** and **Carl J. Lyons,** are the guiding lights of Battelle's Air Quality Team. **Frank** has coordinated environmental sciences and engineering programs at Battelle-Columbus since he left his post as chief of the Office of Resource Development, U.S. Public Health Service. His career has carried him into major sectors of environmental quality, including water and air pollution control, radiation hazards, and the construction of community facilities for abating pollution. **Dick,** as is evidenced by the recognition given to his research on combustion and air quality, is one of the forerunners in the field. Focusing particularly on the problems of industrial and power-plant combustion, he has engaged in studies ranging through smoke abatement, incineration, dust control, and solid waste handling. **Carl,** who is manager of the Department of Biology, Environment, and Chemistry, has headed up Battelle's Environmental Quality Research Task Force. He guides research in the fields of environmental systems and processes for controlling all kinds of pollution, organic and polymer chemistry, and biological and medical sciences.

Dr. Ira L. Whitman and **Richard M. Davis** are mapping out strategies for the regional approach to air quality control. **Ira,** who heads the Environmental Planning Group in the Social and Systems Section is interested principally in the political, institutional, and socioeconomic aspects of environmental quality management. Frequently contributing to environmental research involving inter-disciplinary teams, he has been associated with studies on the effects of highways on the environment, regional air-quality management, water management in the Great Lakes Basin, and many others. **Dick** recently joined the Battelle-Columbus staff as a specialist in systems analysis, to aid in solving resource problems in physical, technological, and socioeconomic systems. His experience in developing strategies or managing water and land resources leads naturally to designing strategies for regional air-quality management.

David A. Trayser and **Frederick A. Creswick** are concerned with evolving clean power plants for autos. **Dave** has devoted almost two decades to theoretical, design, and laboratory studies of internal combustion engines including diesels and Stirling-cycle engines. His interests have included engine dynamics, thermodynamics, and fluid flow problems, with special emphasis on low-pollution engines. Lately, he has concentrated on emissions from autos operating on a chassis dynamometer. **Fred,** with a background in research on conventional and gas turbine engines, also has studied refrigerating equipment, heat transfer, and thermal design. In recent years, he has focused on power plants, including Rankine-cycle-engine boilers, gasoline-engine induction systems, unconventional low-pollution power sources for autos, and Stirling-cycle and free-piston engines.



Study in Environmental Benefits Versus Technological Costs," **SAE Preprint No. 700182**, 1969. Alternative power plants for autos are treated in "Unconventional Thermal, Mechanical, and Nuclear Low-Pollution-Potential Power Sources for Urban Vehicles," by J. A. Hoess and R. C. Stahman, **SAE Preprint No. 690231**, 1969. "Alternative Fuels for Control of Engine Emission," by E. S. Starkman and others, **Journal of the Air Pollution Control Association**, February, 1970, discusses possible fuels. Current emission-control systems are summarized in "The 1970 General Motors Emission Control Systems" by J. B. King and others, **SAE Preprint No. 700149**, 1970.

Basic smog chemistry is reviewed concisely in A. J. Haagen-Smit's and L. G. Wayne's "Atmospheric Reactions and Scavenging Processes" in **Air Pollution**, A. C. Stern, editor, second edition, v. 1 (Academic Press, 1968), and in R. D. Cadle's and E. R. Allen's "Atmospheric Photochemistry," **Science**, January 16, 1970. Book-length treatments are given by P. A. Leighton in **Photochemistry of Air Pollution** (Academic Press, 1961), and by C. E. Junge in **Air Chemistry and Radioactivity** (Academic Press, 1963).

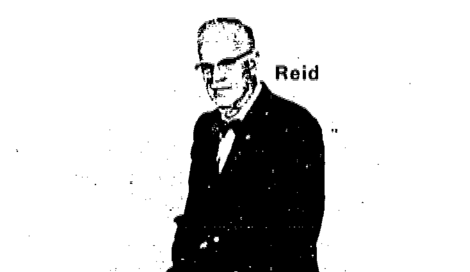
"What 40 Electric Utilities Are Doing for the Air, the Water, and the Land," **Electrical World**, June 1, 1970, describes self-policing by the electric utility industry. The challenges of future electrical demand are highlighted in "1970 Annual Statistical Report, Part 2," **Electrical World**, March 2, 1970. The interaction between engineering assessment and public concern over pollution from central-station power plants is outlined by E. Reinecke in "Pollution—Political Expediency and Technological Competence," **Mechanical Engineering**, July, 1970.

Approaches to atmospheric dynamics and pollutant dispersion in air quality control are treated in a wide variety of sources. The potential of computer modeling is discussed by K. L. Caulder in "Some Miscellaneous Aspects of Current Urban Pollution Models," **Symposium on Multiple Source Urban Diffusion Models** (University of North Carolina, October, 1969). E. P. Ferrand characterizes atmospheric features peculiar to cities in "Urban Air," **Science and Technology**, June, 1969. How land-use planners can employ knowledge of atmospheric dynamics is covered by F. N. Frenkiel in "Atmospheric Pollution and Zoning in an Urban Area," **Scientific Monthly**, April, 1956; in spite of its age, this is still informative. H. A. Panofsky's "Air Pollution Meteorology," **American Scientist**, Summer, 1969, deals with the use of tall stacks to disperse pollutants.

Photochemical smog can soon become a trace of its former self with men like **Arthur Levy, Dr. William E. Wilson, Jr.**, and **Salo E. Miller** attacking it. **Art** has spearheaded Battelle's activities in pollution chemistry, including the chemistry of the atmosphere, combustion, photochemical smog, and other interactions of auto exhaust in and with the atmosphere. He guided recent studies on interactions of SO_2 in smog formation and kinetics of sulfur oxidation in combustion, as well as the aerosol and organic solvent investigations outlined in the smog article. **William**, who is in charge of Battelle's mobile air-quality laboratory, has special interests in the kinetics and mechanisms of photochemical smog reactions, simulation of atmospheric reactions in both large and small smog chambers, and computer simulation of smog formation. **Si Miller** supervises smog chamber operations, and thus has participated in many of Battelle's smog formation studies, particularly in assessing the role of solvents. He was concerned earlier with zone purification of seawater.

A likely place to find **William T. Reid** is around a power plant. He cut his research teeth on fuels studies, and was active in critically investigating the causes of boiler corrosion. Over his 24 years at Battelle, **Bill** has been immersed in energy conversion studies, fuel cell research, sulfur fixation by lime and magnesia, and the basics of corrosion and deposits in boiler furnaces and gas turbines. Recipient of the Prime Mover and the Percy Nicholls Awards, **Bill** last year was given the prestigious Melchett Medal.

Dr. Philip R. Sticksel and **Dr. Stephen D. Ban** are teaching the computer to solve problems in the atmospheric dispersion of air pollutants. **Phil's** background as a meteorologist has led naturally to his work in atmospheric dynamics. Among his areas of interest are the dispersion and diffusion of airborne contaminants, simulation modeling for air quality management, the study of visible emissions including stack plumes and plume rise, and the statistical evaluation of air pollution data. **Steve's** forte is fluid mechanics, with special emphasis on unsteady boundary-layer flows and gas dynamics. In the past few years, he has worked on problems ranging from reentry ablation analysis and techniques for solving urban boundary-layer problems to the flow of dye in yarn and the modeling of vortex production in furnaces.



Selected Staff Publications

The Melchett Lecture, 1969. The Energy Explosion. Since it is people who use energy, the combination of a swiftly growing population and an ever-increasing use of energy per capita is leading to an unprecedented energy demand, which calls for the best efforts of all fuels technologists. Energy servants, subsisting on coal, petroleum, gas, and uranium, can perform tasks that no man can handle, and in numbers that are hundreds of times greater than our human population. The cost of this energy varies widely, though most of it is available at a reasonable price. The author describes the present availability of energy and looks to the future. **William T. Reid.** *Institute of Fuel, Journal,* v. 43, no. 349, Feb. 1970, p. 43-51.

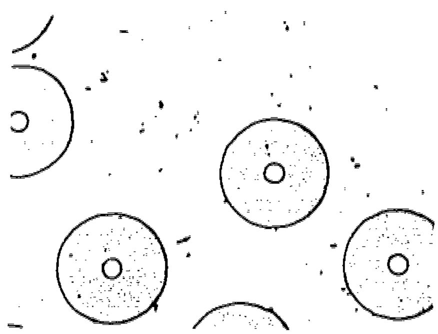
The Systematic Approach to Industrial Development Research. This presents a research program for narrowing the scope of industrial development activities to those having the greatest potential for a region. A major output of such a program is identification of industries that are best suited to the region. In step one, interested groups in the region define the objectives that they have for an industrial development program. In step two, the resources that the region offers to new or expanding industries are evaluated, with emphasis on the region's existing industrial structure. The analysis of resources permits drawing conclusions as to the comparative advantages of the region. **David C. Sweet.** *AIDC Journal,* v. 5, no. 2, Apr. 1970, p. 21-32.

Equipment for the Working Diver. 1970 Symposium Proceedings. In view of the growing demands on divers in regard to work output and working depths, their equipment must be designed to satisfy their needs as dictated by the working environment. Reflecting this, papers given at the symposium (sponsored jointly by the Office of the Supervisor of Diving, U.S. Navy, Battelle-Columbus, and the Marine Technology Society) dealt with equipment design, particularly as it relates to diver safety and comfort; with accessory systems—carbon dioxide removal, communication, power plants, and tools; and with diving operations—deep diving systems and recovery techniques. **Dolores M. Landreman,** editor. 1970, 478 pp. Marine Technology Society, Washington, D.C.

Membrane Science and Technology. Industrial, Biological, and Waste Treatment Processes. This is a book of papers given at a conference on membranes held at Battelle-Columbus last year. The first two, fundamental in nature, discuss and interpret phenomena relating to the transport of both large and small organic solutes within and through polymeric membranes. Five papers are concerned with applications of membranes to solutions where macromolecular compounds, mainly of biological origin, must be separated, purified of dissolved ions, or fractionated. Two papers deal with transporting small dissolved ions for the production of chemicals and for prospective hydrometallurgical separations. The final four papers describe the use of membrane processes in industrial water and waste-treatment situations. **James E. Flinn,** editor. 1970, 234 pp. Plenum Press, New York.

Future Trends and Developments in Adhesive Bonding. The authors list the important advantages of adhesive bonding. However, the article deals mainly with some of the problems of adhesive bonding and discusses approaches being taken to solve them. **Charles W. Cooper and William R. Dunnavant.** *Adhesives Age,* v. 13, no. 2, Feb. 1970, 4 pp.

Factors Affecting the Production of Microbial Food Flavors by Submerged Culture Methods. Two fungal food-flavoring products can be produced by submerged culture of the mycelium: (1) mushroom mycelium, and (2) blue cheese flavoring. Of the genera of mushrooms that have been grown in submerged culture, Morchella spp. have the most satisfactory flavors. Pencillium roquefortii grown in submerged culture produces blue cheese flavor. Either a flavoring extract or pellets from the mycelium can be used as a flavoring additive. Factors affecting the growth of the fungi and their flavor include the substrate and its pretreatment, the nitrogen source, trace nutrients, aeration and agitation, pH, and temperature. **John H. Litchfield.** Paper from *Developments in Industrial Microbiology,* v. XI, 1970, p. 341-349. American Institute of Biological Sciences.



Non-Conventional Fabrication of Metal Matrix Composites. Literally dozens of techniques for fabricating metal matrix composites have been studied over the past few years. Relatively few have been totally successful and fewer have been reduced to commercial practice. One of the promising composites, pictured here (at 300X), utilizes boron fibers in a titanium matrix. **James N. Fleck** reviews the status of several promising, nonconventional processing methods, including isostatic hot pressing, explosive consolidation, and in-situ fibering, in *SME Technical Paper No. EM70-125,* 1970, 11 pp.

Solid Waste Processing: A State-of-the-Art Report on Unit Operations and Processes. The major processes covered are densification and size reduction, separation, sanitary land fill and open dumping, incineration, chemical processing, and recovery and utilization. In addition to more than 550 references, the publication includes the results of a survey on solid waste regulations. **Richard B. Engdahl** and Battelle-Columbus staff. *PHS Publication No. 1856,* 1969, 72 pp. Bureau of Solid Waste Management, Environmental Control Administration, Department of Health, Education, and Welfare. (Superintendent of Documents, Washington, D.C. 20402 at $0.75. Single copies available free, as supplies permit, from Bureau of Solid Waste Management, 5555 Ridge Avenue, Cincinnati, Ohio 45213.)

Molecular Orbital Studies in Chemical Pharmacology. A new area of research discussed at a symposium held at the Battelle Seattle Research Center in October, 1969, was the application of quantum mechanics to the study of drug molecule structure and new drug design. Studying the primary level of chemical events is expected to lead to an understanding of biological phenomena. Since such events are governed largely by the properties of the valence electrons of molecules, molecular orbital theory promises to assist in predicting biological phenomena. **Lemont B. Kier,** editor, 1970, 290 pp. Springer-Verlag, New York.

Cooperative Research in Metalworking. This presents a cooperative program that was designed to determine the reproducibility of measurements (loads required for the forward-rod cold extrusion of steel into standardized specimen shapes) taken by different laboratories during a simple extrusion operation. The results were expected to be useful in several ways: to judge the precision of data on extrusion forces as reported in the literature; to indicate possibilities of experimental errors to laboratories reporting unusual results; and to provide a background for planning and interpreting the results of cooperative programs to be undertaken in the future. **Francis W. Boulger and J. L. Remmerswaal.** *Preprint No. MF 70-915,* 1970, 12 pp. + tables and figures. Society of Manufacturing Engineers.

Development of a Process Utilizing Heated Rolls for Hot Rolling Metals. Described here are the results of several programs for assessing the effectiveness of heated rolls in hot rolling. Heat-transfer analysis of the hot-rolling process was the basis for predicting the quantitative effect of rolling variables on the distribution of temperature in rolled strip. The ductile/brittle transition temperature of the starting material, together with appropriate physical and mechanical property data on the strip and roll material, was programmed into a computer to predict temperature gradients across the strip thickness. Subsequently, tungsten strip was used in small-scale rolling trials. **Alexis A. Popoff, Jed**

A. Walowit, Subash K. Batra, and Robert J. Fiorentino. *SME Technical Paper No. MF70-123*. 1970. 29 pp. Society of Manufacturing Engineers.

Development of a Fluidized-Bed Technique for the Regeneration of Powdered Activated Carbon. The study was directed toward development of a technique for regenerating spent powdered carbon by a fluidized-bed technique. Two systems were considered: regenerating dried spent carbon during its passage through a fluidized bed of an inert material; and using finely divided regenerated carbon as the bed material in a pulsating fluidized-bed system. **Allan K. Reed, Ted L. Tewksbury, and G. Ray Smithson, Jr.** *Environmental Science & Technology*, v. 4, no. 5, May 1970, p. 432-437.

New Ways To Clean Steel for Porcelain Enameling. Procedures adopted recently for the preparation of steel, cast iron, and aluminum for electroplating deserve evaluation for their effectiveness in preparing metal for porcelain enameling. Anodic alkaline cleaning, ultrasonic alkaline cleaning, electrolytic nickeling, and electrolytic chromate coating are described and their possible uses in enameling are discussed. **William H. Safranek and Russell B. Bennett.** *Appliance*, v. 27, no. 6, June 1970, p. 65 + 2 pages.

Two Models of Man. The behavioristic and the phenomenological models of man are presented. Analysis of both leads to these conclusions: (1) the acceptance of either the behavioristic or phenomenological model has important implications in the everyday world, (2) there appears to be truth in both views of man, (3) a given behavioral scientist may find both models useful, depending upon the problem under study, and (4) the behaviorist and the phenomenologist should listen to one another. **William D. Hitt.** *Intellectual Digest*, May 1970. 8 pp.

Organic Coatings in the Ocean. Marine painting problems are complex because of varied and rigorous exposure conditions and the compromises that often are required to expedite the actual painting. This article describes specific coatings that protect against corrosion and discusses antifouling coatings. **Louis J. Nowacki and Richard J. Dick.** *Oceanology International*, v. 5, no. 6, June 1970, p. 30-33.

Astrionics Selection and Operation on Interplanetary Missions. Astrionic subsystems for automated spacecraft designed for interplanetary missions are selected by evaluation techniques that are based on mission requirements, mission event schedules, and spacecraft design characteristics. These techniques provide a measure of system performance: they aid in the evaluation of competitive subsystems and in the preliminary design of conceptual subsystems; and they are used in determining the effectiveness of navigation updating and midcourse correction schedules. Various astrionic systems were evaluated on different schedules for a Jupiter flyby mission by computer programs based on these techniques. **Ellis F. Hitt and Fred G. Rea.** *Journal of Spacecraft and Rockets*, v. 7, no. 3, Mar. 1970, p. 237-242.

The Use of Novel Rosin Derivatives in Pressure-Sensitive Adhesives. Rosin derivatives have long been used as tackifiers in pressure-sensitive adhesives. Described here are the results of a screening program devised to evaluate 13 novel rosin derivatives in natural, butyl, and styrene-butadiene rubbers that were applied to cellophane, Mylar, and polyethylene without a primer. **David A. Berry.** *Naval Stores Review*, Feb. 1970, p. 7-11.

The Socio-Economic Dimension of Water Management. The socio-economic dimension of water management is best viewed within the framework of the total management process. The first step is defining and inventorying the existing water-resource system. Data are needed on the population and employment of the region and on the physical characteristics of the water resource. System goals must be defined and compared with the elements of the existing system—an extremely complex process. The state of the art is not yet up to this task. However, great progress is being made in developing simulation models of water-resource systems, such as the Susquehanna River Basin model evolved at Battelle-Columbus. **David C. Sweet.** Paper from *Dimensions of Water Management*, Mar. 24, 1970, p. 12-20. American Water Resources Association, Ohio Section, and Ohio Department of Natural Resources, Columbus, Ohio.

Evaluation of Methods To Alleviate Corrosion Fatigue in Type 135 Drill-Pipe Steel for Offshore-Drilling Applications. Methods of modifying the drilling environment and changing the response of the material to the environment were examined as means of alleviating corrosion fatigue in Type 135 drill-pipe steel in offshore-drilling applications. The authors compare the fatigue behavior of specimens in seawater and in air with results obtained in deaerated seawater, freshwater, and seawater drilling mud; in inhibited drilling mud; and in drilling mud with an increased pH. Cathodic-protection studies at various current densities applied during fatigue cycling in seawater gave a range of current densities that improved the fatigue behavior. The half-cell potential was determined for the steel in seawater, and zinc was selected as the sacrificial metal coating. **D. E. Pettit, D. W. Hoeppner, and Walter S. Hyler.** Paper from *Special Technical Publication 462*, 1970, p. 241-257. American Society for Testing and Materials.

Design for Welding Offshore Structures. This discusses 12 basic factors that are considered important to the practical and economic design of offshore structures. When these factors are understood, coordinated, and properly applied by design and manufacturing engineers, as well as on-the-job supervisors and craftsmen, weldments can be produced at a realistic cost and on schedule, and can have the properties needed to provide reliable service. **Robert W. Bennett.** *Preprint No. OTC 1230*, 1970, 16 pp. Offshore Technology Conference, Dallas.

New Process for Titanium Powder Metallurgy. Titanium alloy shapes made by hot isostatic pressing have properties equal to, and possibly better than, those of wrought material, and are produced with little or no scrap. The author presents information on tensile properties, microstructure, and chemistry for the Ti-6Al-4V alloy. **George H. Harth, III.** *Precision Metal*, v. 28, no. 4, Apr. 1970, p. 43-45.

Ferrous Charge Materials for Melting Unalloyed Cast Irons in Foundry Electric Furnaces. The authors highlight the advantages of metallized ores as ferrous charge material, as compared with pig iron and scrap. There are good arguments in favor of using metallized ores; foundrymen should give sponge iron and pellets a good hard look. **H. W. Lownie, Jr., and Spencer A. Schilling.** *Modern Casting*, v. 57, no. 4, Apr. 1970, p. 72-73.

The 1970 Census—A $200 Million Aid to Business Planning. Data from the 1970 Census will be more usable by businessmen and governmental planners than has been so previously. Special address coding guides have been prepared for most major metropolitan areas to permit tabulations for any small geographic area of interest. Moreover, computer tapes containing detailed information that will not be included in reports to be issued, will be available well ahead of the reports, so that analyses can begin quickly. The Battelle 1970 Census Center is receiving the tapes. Computerized maps of the type shown here are made up from the tapes; this is one technique used at the Center to facilitate displaying and analyzing the vast amount of data. **Joseph W. Duncan** characterizes the 1970 Census data and their potential usefulness—and also lists the subject items covered by the form—in *Columbus Business Forum*, v. 8, no. 2, Mar. 1970, 3 pp.

HOW TO OBTAIN COPIES. Reprints of many of the papers and articles (but not parts of books) listed here may be obtained by writing the Publications Office, Battelle-Columbus, 505 King Avenue, Columbus, Ohio 43201. Copies will be provided at no charge so long as the supply permits.

POLICY FORMULATION AND IMPLEMENTATION

Modern man has become a multi-organization creature. The individualistic existence that typified the settling of the country is a dying phenomenon. The frontiersman is as remote from us as the unblemished country he pioneered. Increasingly, we lead many-sided lives with attachments to a variety of organizations — professional, social, political, economic, artistic, and cultural. New organizations appear that serve needs new and old as old groups persist in serving yesterday's causes and past passions.

The entanglement of organizational ties, loosely or closely held, leads to greater interdependence in our many activities. This myriad of organizations characterizes and influences our day-to-day existence. Each organization has creeds, goals, objectives, and vested interests; each seeks to expand its sphere of influence (often in a self-seeking way). Certainly the large institutions — government, corporations, unions, and churches — vie for our attention and participation. This pluralism has protected us from the excesses of radical ideologies, but it carries liabilities also. Indifferent institutions in a fluid social landscape can lead to polarization and confusion.

How do these organizations discard the extraneous and add on the new and contemporary, while maintaining a balance to become more relevant in a changing society? Specifically, how does an organization's mechanism sense the changing environment, relate pertinent changes to its own existence, structure and restructure its objectives and operations to accommodate the changes, and ultimately relate these changes to its ongoing activities? These questions and the entire related area of organizational planning in a complex, changing society supplied the groundwork for a seminar devoted to "Policy Formulation and Implementation." The Department of Social and Management Systems at Battelle-Columbus recently invited five speakers to contribute their thoughts on this theme from various vantage points. The speakers and their selected areas of concern were:

Keynote: Donald A. Schon, President, Organization for Social and Technical Innovation

Research Institutions: Roger L. Merrill, Director, Battelle's Columbus Laboratories

Government Institutions: Andrew A. Aines, Executive Office of the President, Office of Science and Technology

Corporate Institutions: Jack E. Goldman, Group Vice President for Research and Development, Xerox Corporation

Wrap-Up & Reflections: James E. Mahoney, Program of Policy Studies in Science and Technology, The George Washington University.

The following is a brief summary that suggests some of the interesting points made during the seminar.

Organizations and Obsolescence

It's all too easy for organizations to fall behind the times, to fossilize. This is especially true for governmental organizations, which often lack a yardstick for measuring their effectiveness. In governments, the complications of civil service, patriotism, and politics tend to smother logic with lethargy and emotion. Often governments choose politically expedient paths in dealing with hot-potato problems. Aines observed: "Most government agencies have come into being at least a decade after identification of need."

Such laggard action is much less typical of the marketplace and of the capitalistic system, imperfect as they are. Business and industry are more likely to come up with increasingly effective mechanisms to displace the less efficient ones. Of course, the corporation, too, may be trapped when its dominance in a market leads to complacency. As times change, relevance of organizations changes, too. Thus, the buggy whip industry, as such, was doomed to failure with the coming of the auto. But, as Goldman noted, the buggy whip companies might have averted disaster if they had redefined their business as "vehicle acceleration." He pointed out that to take the right path, they should have asked the proper question: "What is it that is likely to render our business obsolete?" — and proceeded to get the correct answer. Then they might have found a place in a burgeoning industry.

Orientation to Change

For most organizations lethargy is typical and lightfootedness is an exception. Success, growth, and tenure all nurture rigidity. Indeed, some argue that institutions are the stabilizing factors in a society, lending continuity to counterbalance the excesses of change. Many of today's heated issues revolve around this thesis.

But change is indeed an integral part of today's society, and our institutions should in some way integrate change-sensing and change-implementing mechanisms into their operations. Contemporary institutions in government, business, and education, once untouchable, now are open targets; their size, age, and power no longer protect them from, but rather have become the basis of, sharp criticism. And all too often, the battle is highly polarized, as John Gardner once eloquently stated, between "uncritical lovers and unloving critics." Criticism has always existed. "What is *new* today, however," Merrill stated, "is the widespread extent of this questioning as a result of the universality of education and the material affluence brought about by technology."

History abounds with examples of organizations structured for inflexibility

Donald A. Schon

Roger L. Merrill

and unresponsive when the weight of evidence cried out for change: In World War II, the French generals doggedly held to an outdated war strategy; in business, the auto industry responded very tardily to a significant import threat; and in government, Federal transportation policies remain geared to an era of 30 years ago.

Creating change-oriented organizations or institutionalizing change in existing organizations presents awesome challenges. Yet, how can organizations stay relevant in our society unless they somehow orient themselves to newly perceived threats and opportunities?

Threat-Sensing Organization

Possible dangers rather than opportunities dominate our thinking as individuals and in organizations. Mahoney believes: "Most organization policy groups are structured in such a fashion as to be extremely responsive to threats." Threats challenge our past policies and endanger our "stable state." The latter factor presents perhaps the greatest call to arms, since organizations are geared for continuity and, according to Schon, "the loss of the stable state" creates tremors of the first order.

In today's context, university administrations, industrial firms, and an institution as basic as the family are confronted with questions, criticisms, and recriminations for which they are entirely unprepared. Without making value judgments, we usually see this censure met defensively, rather than with consideration of its merits. Organizations should ask: "What's in this criticism that will be useful to our organization? How can we improve what we're already doing? What should we do that we haven't been doing?"

The responses by the embattled defenders of the organization under attack amply confirm the thesis that the defense of one's equity in a past position is totally emotional, while the perception of the opportunities that are smothered under the rhetoric, bluster, and emotionalism of most criticism is a wholly intellectual experience. Is it possible to sense opportunity within impassioned criticism? It's hard, since much of the criticism is negative and lacks constructive content. Yet our society sorely needs organizational mechanisms, especially in the larger and more established institutions, to sense the positive contributions that can be extracted from perceived external dangers. Overall, the defensive and often myopic stance can never be beneficial, since it leaves the critics and the criticized without a meeting place for discourse.

Periodic Life / Death Reappraisal

Unlike human beings, who have a finite life span, institutions can go on for centuries. Few organizations have willed themselves out of existence; and when they cease to exist, some outside cause is usually responsible, e.g., government fiat, war, or the fickleness of the marketplace.

Institutionally, organizations would undoubtedly benefit if their charters required a periodic life/death appraisal by some agency, internal or external, that had the appropriate objectivity and competence. This may seem like an extreme position, but responsible managers should — and many do — periodically (and incisively) review their objectives in the light of changing events and circumstances. By so doing we practice on an institutional scale what we do individually in a lesser way — dispose of properties or goods that no longer meet our needs and replace them with those that do. Mahoney suggests that we should create organizations that have a finite period of life. A less radical, but worthwhile, approach would require the organization periodically to argue why it *should* be allowed to continue, at least in its then-current form. And if the organization be dissolved, the action should be complete and final.

Need for Large-Order Change

Increasingly and often shockingly, we are confronted with problems of such magnitude that the means to a solution — even an improvement — are not apparent. Sometimes the mechanisms at our disposal are ill-adapted to meet the problems we face. Somehow even the most complex physical problems, such as landing a man on the moon, shrink in comparison to those involving basic human and social values. How resolute we are in the face of a difficult physical problem, but how impotent we often seem when confronting complex social problems. As Schon observed: "The management of large-scale programs aimed at institutional and social change is something we do not know how to do."

Ubiquitous critics persist in reminding us that we subordinate human values to material ones. No doubt there is some justice to this argument but also undoubtedly these critics, especially the more vehement ones, have serious shortcomings, too. They often are guilty of lacking evenhandedness when they carp about

Andrew A. Aines

Jack E. Goldman

James E. Mahoney

what's missing, without acknowledging what's good. They also show no sense of historical perspective when they fail to compare fairly what we have, faults notwithstanding, to the totality of what other societies had before.

But, as mentioned previously, censure of the most distasteful kind may also carry the kernel of a very worthwhile argument. On too many issues we have been tardy and oblivious, especially to those needs requiring a major effort in unglamorous arenas. As Aines put it: "We're much more apt to get action in a noble-like area, like environmental pollution, than in, say, merchant fleet rehabilitation." No panaceas exist for many difficult problems facing us today; the difficulties have mushroomed in an era of indifference. Where the problems are biggest we often need quantum changes, not just evolutionary improvements. Often our institutions are poorly equipped for such action, and our lack of resolve compounds their inadequacies.

Technology: Good and Evil

The consequences, both good and bad, of the onrush of science and technology must be considered here. Only recently have we begun to realize the extent to which science and technology can lead to evils as well as to good. Many of the evils could be prevented, or at least greatly abated, by properly controlling and balancing technological developments. Unfortunately, the measures we have taken for ameliorating technology's ill effects have been faulty and erratic, at best. Those who cry for a freeze on scientific and technological progress are shortsighted, for as Merrill points out: "It is only man's misuse of science and technology that poses a threat."

There is no doubt that our world is becoming more technology-intensive and, therefore, the problems arising from the dichotomous nature of technology will not solve themselves. Often it seems that the pace of technological progress is greater than the rate at which we are capable of digesting and using it to advantage. On occasion we do retrench unwittingly. As Goldman commented: "When things get tough, the first thing to cut is the research project." Corporations can unilaterally slash their R & D budgets; should the nation do likewise? If change is a characteristic of a vital society — and it is — then certainly technological progress is important to society's health. On that basis, retrenching on research appears to be highly unwise. At the same time, change-oriented institutions must consider both the beneficial and the damaging aspects of the science and technology that their research creates.

Herbert S. Kleiman

Views & Previews

High-Level Manpower in the 70's

However important good management has been in the past, it will be all the more critical in the future. Organizations must adapt to the growing sophistication of the economy, to the shift of emphasis from hard goods to services, and to the increasing concern for higher standards of living including upgraded services, education, medical care, and environment. Meeting the demands will call not only for improved technology, but also for more efficient management. Finding the manpower to achieve these goals is going to be a real challenge for organizations.

Addressing himself to this situation, Dr. Joseph W. Duncan of Battelle's Department of Social and Management Systems told the National Management Development Conference of the Mortgage Bankers Association that changes in the age of the U.S. population will greatly complicate the management-personnel picture. He pointed out that declines in the number of people within the middle age groups will mean leaner pickings in getting the usual managerial types. While employable workers in the 25 to 34-year age group will increase 47 percent by 1980, the 35 to 44-year group — where middle management is usually found — will grow only 12 percent, and the 45 to 54-year group will shrink 5 percent.

These figures suggest that many management people will have to come from the ranks of recent college graduates. There will be plenty to choose from. The 772,000 receiving bachelor's and first professional degrees in 1970 will swell to over a million by 1980; the 211,000 with master's degrees will go above 380,000; and the 29,000 Ph.D.'s will double.

But what will companies do about the lack of working experience? Current hiring experience shows that management types move into specific positions from a variety of educational backgrounds. Factors other than formal training often count more. These may be creativity, analytical ability, supervisory capabilities, or fundamental skills that are adaptable widely.

The Battelle-Columbus socioeconomist concludes that continued economic and social progress depends upon the careful selection and use of our human resources in management, research, and other high-level activities. He suggests that organizations can employ manpower more effectively if they apply these management principles:

- Delineate the organization's mission by establishing specific operating objectives.
- Set up a well-defined organizational structure designed to carry out the firm's objectives and to serve its markets and customers.
- Systematically measure progress in meeting the set objectives, in order to evaluate operating performance and to furnish a base for improving it.

The Chemical Industry and Change

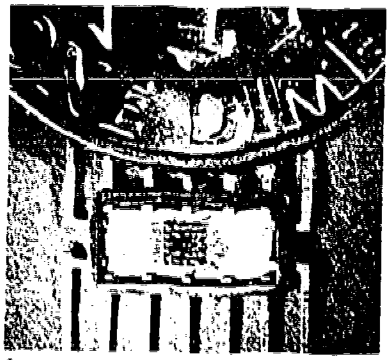
Like others, the chemical industry will have to do some changing, and will have to withstand the conflicts and seize the opportunities that come with change. This was the message of Edward S. Lipinsky, chemical economist at Battelle-Columbus, to members of the Commercial Chemical Development Association at a recent meeting in Cleveland.

He noted various reasons for this prognosis:

- Altered conditions can kill older processes or lead to substantial modifications of them.
- When the end products of processes that are inherently high in cost are adapted for extensive use — e.g., the high-strength composites identified with aerospace activities — the industry can profit, but only by expending considerable ingenuity, capital, and planning effort.
- More intensive usage of many processing systems is likely to result in pollution that will be tolerated less and less; control of such pollution is bound to generate the need for technological changes.
- New interactions between systems can force change, as when fertilizer runoff must be reduced to help save the waters of our rivers.

Lipinsky sees more opportunities in user-oriented systems than in commodities. For example, as the auto industry turns more and more to modules in car designs, great opportunities are uncovered for the chemical industry. Better temperature-resistant, lightweight, strong materials will certainly find a market here. There will be a need, in turn, for processes to produce and shape these materials and for methods of decorating

Detecting Microcircuit Defects. As more complex microcircuits are crowded on semiconductor chips, inspecting the circuits becomes more difficult—especially when reliability is critical, as in devices for space. In a study for NASA's Marshall Space Flight Center, the Battelle-Columbus advanced electronics group used the high magnification and depth of field provided by the scanning electron microscope (SEM) to ferret out and document flaws. Here, micrographs of the microcircuit on a chip that is shown in A display the SEM's usefulness. Micrograph B (25X) reveals the .001-inch gold connector wires, which are attached by gold ball-bonds to thin-film conductors on the chip's surface as pictured in C (250X). Necking of the wire and a possibly catastrophic crack (arrow) that are not visible at lower magnifications are apparent in D (1,000X). The SEM also disclosed scratches



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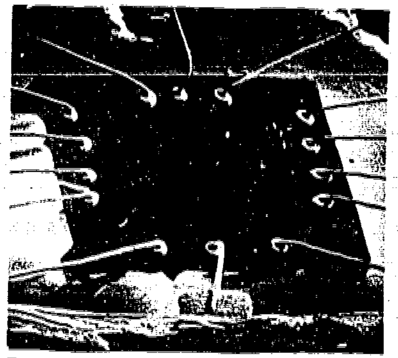

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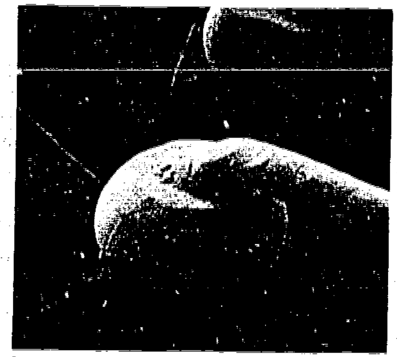

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them — all fertile areas for the industry.

But of all immediate problems, those related to product marketing and distribution seem most critical to the industry. Too often, distributing and servicing products cost three times as much as manufacturing them. The chemical industry must focus on such matters as product transportation, storage, and inventories, which can affect profits so seriously.

The Striker Gets a Ph.D.

Why use a room full of expensive equipment to measure dynamic material properties? Most such measurements, say Battelle's Donald R. Ireland and Dr. William Oldfield, need only the space to permit whacking a little notched bar sharply enough to break it, plus enough room for a big bread box. A few minutes after the striker whacks the bar of sample material, the bread box can tell you things like:

- Dynamic yield stress
- Dynamic fracture toughness
- Intrinsic cleavage fracture stress
- Critical crack opening displacement
- Crack velocities
- Various energies related to the start and continuation of fracture.

Break the bar at a couple different temperatures and you can add a few transition temperatures to the list — the ductile/brittle transition temperature, for instance.

If you've had experience with mechanical property testing, you know that the whack with the striker is the essence of the Charpy impact test — a fine, old, easy-to-run, inexpensive method for determining resistance to impact. Up till now, the Charpy test has given only one number, but Ireland and Dr. Oldfield have upped its sophistication a few orders of magnitude — so as to give several numbers.

You see, in the few microseconds between the hammer's contact with the bar and the bar's breaking in two, a complex series of events takes place. First the bar bends like a spring — elastically. Then it yields grudgingly, acquiring a permanent bend. Next, it starts tearing in a ductile way, that is, as if it were soft like putty. Then it cracks rapidly in brittle fracture like a piece of glass. Finally, it tears completely apart. Now these materials engineers have come up with a method to record this step-by-step process automatically and to analyze it for a variety of information.

They started by fitting a strain gage to the striker; whatever happens in the specimen bar shows up as strain in the striker. The gage passes this strain along to the bread box as an electrical signal. Of course, this is a pretty fancy bread box. However, these fellows assure us that it can be put together in a bunch of sizes and models tailored to fit your data needs, your budget, and your flair for living. The bread box can record the behavior of the bar on fracture, and also it can be equipped to analyze the record for the material property data it contains. Obviously, this involves quite a few options.

The way Ireland and Dr. Oldfield like to do it is to record the load/time fracture curve (the cleaned-up strain-gage signals) on magnetic tape. With help from an analog-to-digital converter, they can convert the taped curve into a series of points to which they assign numerical values. The load/time curve can be resolved into points at 350 nanosecond intervals. Finally, a computer programmed for the task analyzes the digital readout.

A utility model of the bread box might include only the instrumentation for cleaning up the load/time curve and for recording it on magnetic tape. Analog-to-digital conversion and computer analysis could be done anytime, anywhere. A top-of-the-line model would include both the converter and a dedicated minicomputer programmed for the whole scope of analytical tasks; it could give results right here and now.

The approach, of course, isn't limited to the Charpy impact test. Other dynamic tests — like the dynamic tensile test — can be instrumented for automatic computer analysis as well.

Look for the computer-assisted, instru-

Better Metal Finishing by Chemically Expediting the Vibratory Method. Immersing metal items in a bed of vibrating polishing material is recognized as one of the least expensive ways to finish metal surfaces. Normally, various-size ceramic or plastic pieces impregnated with abrasives are used in the vibratory beds. Battelle-Columbus engineers have discovered that the process can be accelerated and finishes improved by running chemical polishing agents through the bed during the operation. In the experimental run shown here, Hugh R. Miller is placing a metal specimen into the bed; the specimen will be polished by ceramic pieces as a chemical polishing solution is introduced from above. After flowing to the bottom of the bed, the liquid is recycled for further use.

mented, dynamic-mechanical-property testing equipment — at your friendly, neighborhood instrument maker.

Academy for Contemporary Problems

The Ohio State University and Battelle Memorial Institute have joined forces to establish the Academy for Contemporary Problems in Columbus, Ohio. The Academy's primary functions will be to provide means of adapting institutions and organizations to changing social patterns, of putting knowledge into action, including the transfer of knowledge from one field to another, and of improving communications between institutions — all through the combined application of advanced study and education to defining and solving contemporary problems of man.

Battelle and Ohio State will share equally in funding the Academy's operating costs, which are expected to be about $1 million annually. In addition, Battelle will build a facility for the Academy on a site close to both organizations. Full-scale occupancy is anticipated by 1972.

A board of overseers will direct the Academy. Three members from each parent institution will name a seventh member, who will become the Academy's chief executive. The Academy will be staffed by resident personnel, affiliated with either Battelle or Ohio State, as well as by others specially selected for varying periods of appointment to help with the Academy's program.

Group Research

Your Polymer and Its Skin Problem

Many polymeric materials have bulk properties that are desirable for a variety of applications, but because of unfortunate surface properties their use is limited. For instance, some polyesters have strength, elastic, and fatigue properties that would be ideal for tire cord, but they bond so poorly to the rubber that many advantages of the bulk properties are lost. Or, several polymers could make strong, durable, wrinkle-resistant textiles, but they pick up lint, soil and stain easily, or are highly flammable. If the surfaces of these polymers could be treated to induce the desired characteristics, then their range of application, and thus their commercial value, would be enhanced sharply.

There is hope for these polymers. Under the technical guidance of Dr. Richard A. Nathan of the Organic and Polymer Chemistry Division, Battelle-Columbus has proposed a group research program to exploit an interesting approach to the problem.

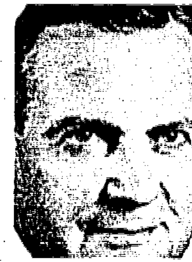
Dr. Nathan, with George E. Cremeans and Dr. Eugene J. Mezey, plans to attach chemical "handles" to the polymer's surface, and to use these handles to graft on molecules that will give the polymer favorable surface properties without disturbing its bulk properties.

The important consideration is that these chemical handles (active groups of atoms) must be added only to the surface layers and at temperatures low enough to prevent the polymer from degrading. This will be approached by using microwave irradiation to obtain low-temperature plasmas of the handle species. Microwaves create the plasma by stressing the molecules of low-pressure gases enough to break the molecules into highly reactive pieces, called free radicals, without any great increase in temperature. Thus, microwave irradiation of NH_3 gas can produce a low-temperature plasma that is rich in active NH_2 radicals; likewise, irradiation of H_2O vapor can create a low-temperature plasma that is rich in OH radicals. The free radicals then join themselves to the surface layers of the polymer and serve as handles for attaching various classes of molecules.

The investigators plan to study a variety of handles selected to improve surface properties such as adhesion, electrical characteristics, dyeability, and fire retardancy. Also, they will assess the technical and economic feasibility of the microwave plasma concept on a commercial scale.

Honors

Francis W. Boulger was elected recently to the Governing Council of the International Institution for Production Research. The organization, with members selected from 27 countries, directs its efforts to the improvement of manufacturing processes and equipment through cooperative research and by international conferences on new technology. Last year, seminars were held in France, Germany, Italy, and Switzerland. Fran, a Senior Technical Advisor, has been on the Battelle staff since 1938. He has been and is closely associated with research on the shaping of metals, particularly metal forming and cutting.



Dr. John H. Litchfield has been installed as president of the Society for Industrial Microbiology. The more than 1,000 members of the Society include biologists, mycologists, bacteriologists, chemists, engineers, and others interested in applications of microbiology to agriculture, industry, and public health. John, who is section manager of Biology and Medical Science at Battelle-Columbus, has directed studies in food science and technology, microbiology, biochemistry, pharmacology, physiology, and marine life.

Professional Posts

Staff members recently named to professional posts include:

C. MALCOLM ALLEN, chairman, Advisory Committee, American Society of Mechanical Engineers.

WARREN E. BERRY, member, Committee on Research, National Association of Corrosion Engineers.

WALTER K. BOYD, chairman, Publication Committee, NACE.

FREDERICK A. CRESWICK, member, Reciprocating and Rotary Compressor Units Committee, American Society of Heating, Refrigerating, and Air-Conditioning Engineers.

DR. RICHARD S. DAVIDSON, member-at-large, Board of Directors, Ohio Environmental Council.

PAUL D. FROST, member, Constitution and Rules for Government Committee, American Society for Metals.

DR. STANLEY H. GELLES, chairman, Subcommittee on Less Common Metals and Alloys, Committee on Nonferrous Metals and Alloys, American Society for Testing and Materials.

Dr. Horace J. Grover, chairman, Committee on Surgical Implants, ASTM.

Dr. Curtis M. Jackson, member, Editorial Advisory Committee, *Wire Journal.*

Dr. Robert I. Jaffee, member, Materials Advisory Board, National Academy of Sciences-National Research Council.

Richard L. Jentgen, member, Annual Meeting Program Committee, American Society of Lubrication Engineers.

Dr. Melvin F. Kanninen, secretary, Committee on Computing, Applied Mechanics Division, ASME.

Dr. James B. Kirkwood, chairman, Symposium on Ecological Problems in the Marine Environment, First National Biological Congress, American Institute of Biological Sciences.

Dr. John McCallum, member, Board of Directors, Electrochemical Society.

A. George Mourad, vice-chairman, Navigation Subcommittee, Anti-Submarine Warfare Advisory Committee, National Security Industrial Association.

Appointments

Dr. Samuel Globe, assistant director—technology. With his new appointment, Sam becomes chairman of the Senior Technical Council at Battelle-Columbus.

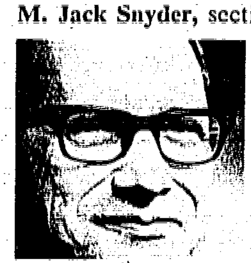
David D. Moore, assistant director—special assignments. In his new assignment, Dave pursues studies that will serve to strengthen staff capabilities in meeting changing R & D requirements.

Perry J. Rieppel, assistant director—technical development. With his appointment, Perry undertakes responsibility for the continuing program designed to develop both technical staff and facilities to satisfy the demands of increasingly exacting contract research.

Dr. Duane N. Sunderman, manager, Department of Social and Management Systems. Duane is responsible for research on business and technical economics, social and behavioral sciences, information technology, and systems analysis.

Paul J. Gripshover, section manager, fabrication technology. Paul guides research on powder materials applications, particulate metallurgy, and materials development, technology, and application.

Dr. David L. Morrison, section manager, environmental systems and processes. Dave's concern includes: analysis and monitoring of the environment as a physical and ecological system and from the viewpoint of specific contaminants; understanding physical and chemical phenomena in the environment; development of processes to control environmental contamination; and studies of managing the environment as a resource.



M. Jack Snyder, section manager, inorganic materials. Studies in electrochemical engineering, ceramics, plutonium technology, materials thermodynamics, and thermophysical properties of materials come under Jack's direction.

Dr. Charles W. Townley, section manager, materials science. His responsibilities encompass studies in metal science, materials and environmental engineering, mechanical metallurgy, corrosion, and structural physics.

Dr. Edward W. Ungar, section manager, engineering physics. Ed guides aerothermal research, and investigations in aerospace mechanics, weapons physics, and defense planning and engineering.

Hugh D. Hanes, chief of materials development, supervises research in high pressure technology, solid state bonding, beryllium technology, thermoelectrics, and biomaterials.

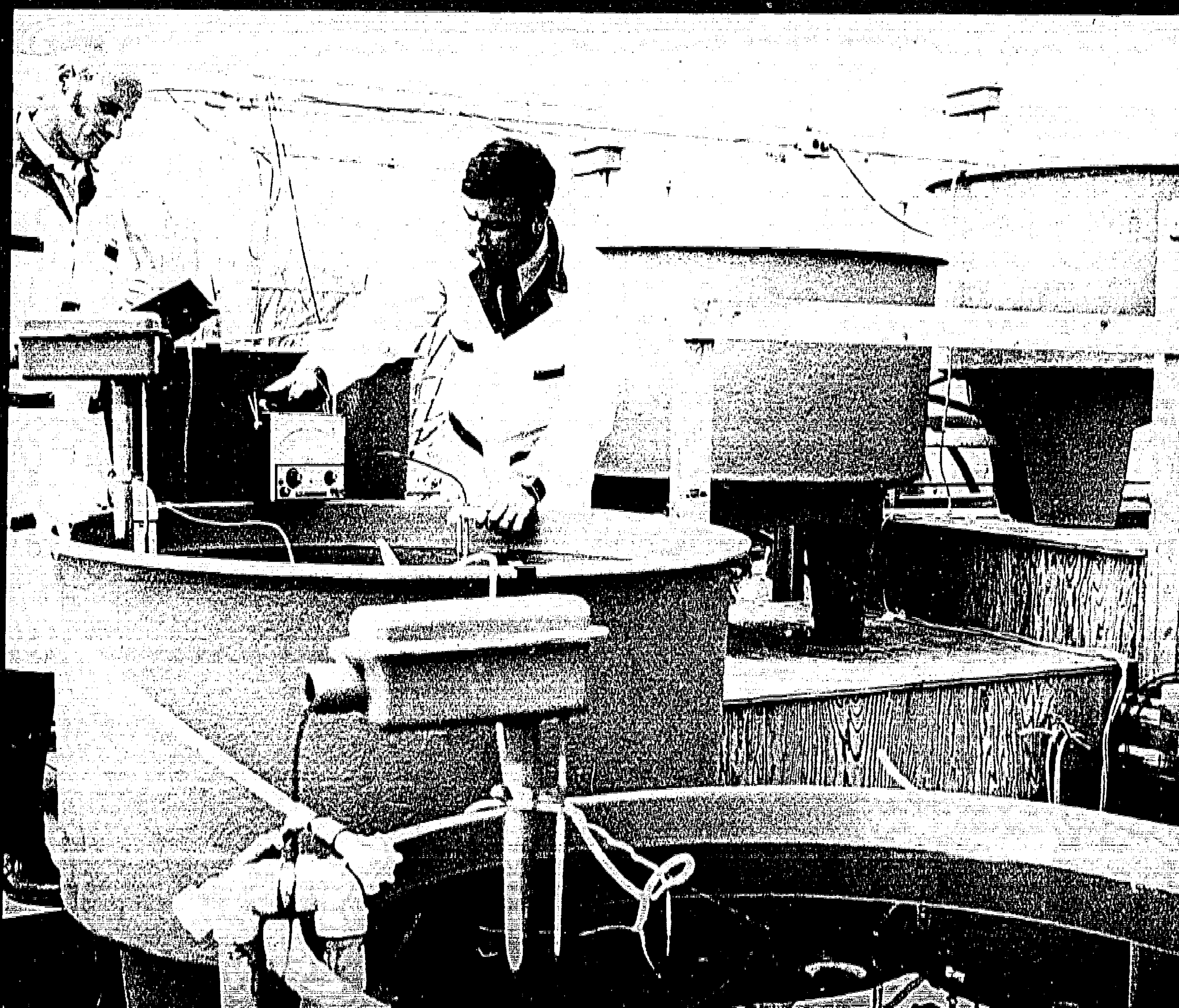
Dale E. Niesz, chief of ceramics research, supervises fundamental studies and process and product development related to a spectrum of materials including: refractories, white wares, glass, carbon and graphite, coatings, composites, and ferroelectrics and ferromagnetics, as well as aerospace ceramics, bioceramics, and inorganic construction materials.

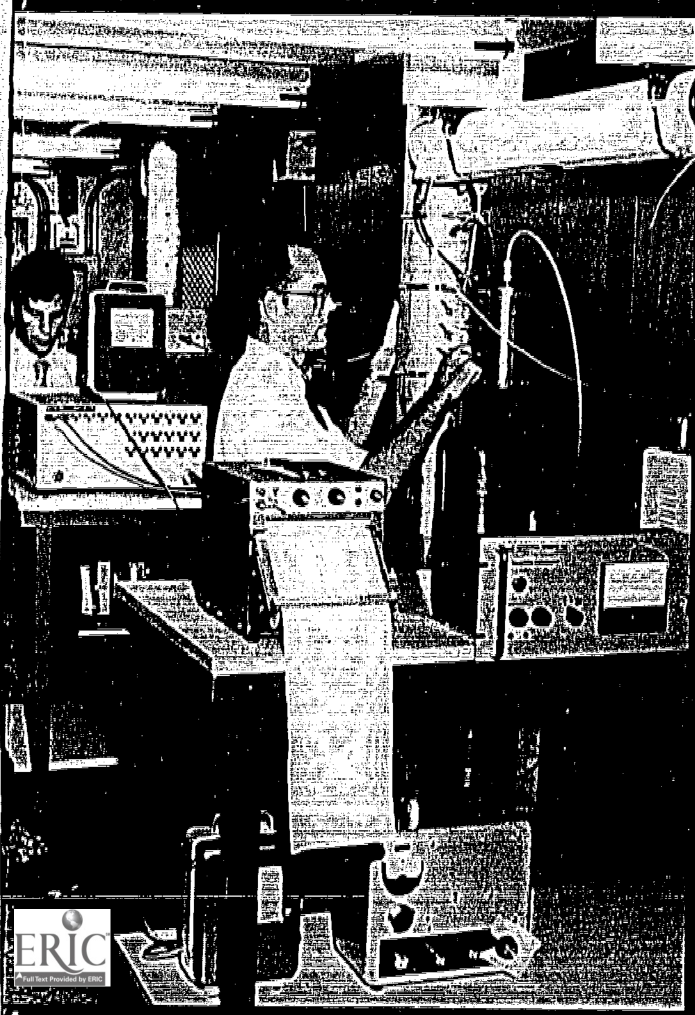
Dr. Gilbert E. Raines, chief of ecology and environmental systems, directs interdisciplinary research that spans planning, managing, and conducting broad ecological studies and solving specific environmental problems relating to nuclear detonations, highways, industrial development, water resources, and both nuclear and conventional power facilities. Gil has a special interest in developing methods for quantifying ecological and environmental factors as a basis for advantage/disadvantage analyses.

George W. Tressel, chief, communications media research, guides the development of facilities and methodologies for enhancing the communication process.

Robert Yereance, chief of engineering physics, directs studies in Xerography, reproduction and duplication, electrostatics, and vacuum technology.

The Research Scene





1—**Effects of Emissions on Vegetation.** Scientists know that power plant emissions can destroy vegetation. But how can you check on such an effect? Photogrammetry makes fast, sure, large-scale assessments possible. This infrared photo, taken for Battelle-Columbus photogrammetrist Joachim G. Stephan, shows browned fir trees that were damaged by stack effluent.

2—**Probing Ecological Problems With Mathematical Models.** This system of tanks is designed to verify the results obtained by mathematically modeling aquatic ecosystems that receive heated effluents. Dr. Thomas J. Birch (right) and Donald R. Taylor of the ecology and biosystems analysis group are monitoring the biological, chemical, and physical characteristics of water pumped from Lake Battelle. After the water is warmed, it is moved on through the system, and its effects on downstream aquatic life are studied. Present Battelle-Columbus models combine data on heat transfer, mass transfer, and population dynamics for the purpose of forecasting how thermal effluents influence river life. Other pollution factors can be treated similarly. With such models, investigators can examine a problem from many sides, identify the data needed, predict changes, and evaluate various strategies for using resources.

3—**How Does a Seaside Nuclear Power Plant Affect the Ecology of the Nearby Ocean?** A current study for Northeast Utilities (NU) System by Clapp Laboratories of Battelle-Columbus will help provide an answer to this question. Scientists have been counting and evaluating living specimens in the seawater near the plant site for some time, for comparison with data to be taken after the plant becomes operational. Here, Dr. Robert Hillman lowers a tray of oyster spat (young oysters) into the plant's discharge canal while Jay Wennemer (right) and Nancy Davis (left) of the Clapp staff and NU environmental specialist William Peterson look on. Comparing the rate of oyster growth before and after plant start-up will provide one measure of the plant's ecological effect.

4—**Mobile Air Quality Laboratory for Field and Specific-Source Sampling.** The 35-foot trailer, which was outfitted at Battelle-Columbus, is equipped with continuous air-quality monitors, a wet-chemistry laboratory for batch-sample analysis, and equipment for extensive analyses of particulates in the atmosphere. This mobile laboratory can monitor most common air pollutants including acid gases and total oxidants and hydrocarbons. Light-scattering measuring equipment onboard can continuously indicate aerosol mass loading and atmospheric visibility. Special gear and techniques permit taking samples of gases and particulates for more detailed analysis in the laboratories at Columbus. Dr. William E. Wilson, Jr. (front) and David F. Miller, shown here using the equipment, collaborated in designing the laboratory.

BATTELLE MEMORIAL INSTITUTE
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Columbus, Ohio 43201

OTHER BATTELLE LABORATORIES OR OFFICES:

In the U.S.A.:
Chicago, Cleveland, Daytona Beach, Detroit, Duxbury (Mass.), Huntsville, Long Beach, Philadelphia, Richland (Wash.), Seattle, Sequim Bay (Wash.), Washington, D.C.

Overseas:
Adelaide, Buenos Aires, Caracas, Frankfurt, Geneva, London, Madrid, Paris, Rio de Janeiro, Sydney.

The Columbus Laboratories of Battelle Memorial Institute perform contract research for industry, government, and other organizations. They provide the personnel, experience, and equipment to solve problems and generate basic knowledge in virtually all areas of science and technology.

Much of Battelle's growth has stemmed from the successful application of the multidisciplinary approach to research, in which specialists from different scientific, engineering, and other disciplines join forces to apply their in-depth knowledge to a problem.

At Battelle's laboratories in Columbus, Ohio, the research focuses on:

- the solution of highly specific and practical problems as well as theoretical explorations on the frontiers of science.
- the design and development of materials, products, processes, and total systems.
- information analysis, technical-economic and socio-economic studies, and marketing and management-planning research.

Battelle research has produced advances in highly diverse fields for sponsors large and small located in 90 different countries.

The staff at Battelle-Columbus includes approximately 1,400 scientists and engineers who are experienced in a variety of disciplines. Supported by an equal number of other personnel, they conduct research in specialized laboratories and other facilities housed in 35 buildings. Battelle-Columbus also operates research facilities at Duxbury, Massachusetts; Daytona Beach, Florida; and Long Beach, California.

Battelle Memorial Institute was established under the will of Gordon Battelle, last of his line, as a memorial to his family. The Battelles were among the first settlers of Ohio and were prominent in the development of the state's iron and steel industry. Operations began in laboratories that today are part of Battelle-Columbus; and corporate headquarters continue to be in Columbus. Other Battelle centers for contract research are now situated in Richland, Washington; Frankfurt, West Germany; and Geneva, Switzerland. Other research sites and offices are located throughout the world; the staff worldwide totals about 7,000.